PUBLIC ROADS

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BUREAU OF PUBLIC ROADS

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A WEIGHING STATION USED IN THE CONNECTICUT HIGHWAY TRANSPORTATION SURVEY

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Traffic on the Boston Post Road near New Haven, Conn. Illustrating the retardation of passenger vehicles by motor truck traffic.

CONNECTICUT HIGHWAY TRANSPORTATION SURVEY.

Conducted by the U. S. Bureau of Public Roads and Connecticut State Highway Commission.

A PRELIMINARY REPORT ON THE FIRST THREE MONTHS OF OPERATION.

By J. GORDON McKAY, Highway Economist, U. S. Bureau of Public Roads.

THE Connecticut Highway Transportation Survey, conducted by the U. S. Bureau of Public Roads in cooperation with the Connecticut State Highway Commission, was begun September 11, 1922, and continued for one year.

The two highway agencies entered into the study—the most intensive and carefully planned census of highway traffic which had been attempted—with the conviction that a large volume of highway transportation facts was a prerequisite to the solution of many of the problems of highway construction and maintenance and highway transportation. They were influenced by no prior beliefs or prejudices, and were committed to an unbiased study of the situation in this one State as an initial experiment to be followed by similar studies on the part of the Federal bureau in other States in which it is hoped to have the cooperation of the State highway departments.

Credit is due to Mr. C. J. Bennett, State highway commissioner of Connecticut during the major part of the period of the survey, and to the personnel of the Connecticut highway commission for their excellent cooperation in obtaining the records.

FACTS DERIVED FROM THE SURVEY SUMMARIZED.

A careful analysis of the results of the survey obtained during the first three months reveals certain definite facts which are set forth in this preliminary report, to be followed as soon as possible with supplementary information in greater detail when the entire year's operation has been analyzed.

The following are the principal facts ascertained in the first three months:

Passenger traffic averages 2.5 persons per vehicle and 45.1 miles per car per trip.

Thirty-five per cent of the passenger movement is primarily for business purposes and 65 per cent for nonbusiness purposes.

Passenger business traffic averages 1.7 passengers per car and the nonbusiness traffic 3 passengers per car with an average trip mileage of 29.7 miles for the business and 55.5 miles for the nonbusiness traffic.

Twenty-three and five-tenths per cent of the passenger mileage in the State is for business purposes and 76.5 per cent is for nonbusiness purposes.

The peak of the highway movement occurs in this State in October and the minimum is reached in February, when motor-truck transportation is 40 per cent and passenger traffic is 70 per cent lower than the October movement.

There is a more rapid decline in motor-truck traffic on secondary highways than on the New York-Springfield route, the main interstate highway through the State.

The percentage of large motor trucks is smaller on the secondary highways.

Motor-truck traffic reaches the daily minimum at 4 a. m., from which time it increases to a first peak between 10 a. m. and 12 o'clock noon and a second peak between 2 and 4 p. m., decreasing rapidly after 5 p. m.

The night movement of motor trucks consists largely of long-distance traffic in special commodities hauled in trucks of large capacity with heavy net loads.

The percentage of overloads is considerably greater at night than during the daylight hours.

The percentages of ½, 1½, 5, and 5½ ton trucks were slightly greater in 1922 than in 1921 in this State and there was a falling off in the percentages of 2, 2½, 3, 4, and 6½ to 7½ ton trucks.

THE PREVALENCE OF OVERLOADING.

Twenty-nine and six-tenths per cent of the trucks operated over the highways of the State were loaded in excess of their rated capacity, but this percentage represented a considerable improvement over the condition observed in 1921, a fact that is attributed to the enforcement of the traffic laws of the State.

Overloading is a practice in which trucks of all makes and capacities are involved, although the indications are that the ½, 1½, and 5½ to 7½ ton trucks are not overloaded as regularly as the 2 to 5 ton trucks, the small percentage of overloading of the 5½ to 7½ ton trucks being attributed in part to the enforcement of the 25,000-pound maximum gross load limit of the Connecticut law.

Sixty-five and two-tenths per cent of the overloaded vehicles are trucks of 1-ton capacity or less.

There is a distinct relation between the width of truck body and the probability of overloading, the percentage of overloads increasing rapidly with increase in body width.

With the exception of the trucks of the 5½-ton class the average trip mileage for trucks of all capacities is less than 70 miles.

The average trip mileage of pneumatic-tired trucks exceeds that of solid-tired trucks in all capacities except the ½ to 1½ ton group.

The average net load per vehicle is greater in solid-tired trucks of all capacities than in pneumatic-tired vehicles.

The net loads carried on extra-State trucks average greater than the net loads carried by Connecticut trucks.

The use of the Connecticut highway system by foreign trucks, on a ton-mile basis, is greater than the use by Connecticut trucks.

Connecticut trucks, constituting 89 per cent of the total motor-truck traffic, transport 86.5 per cent of the total net tonnage and account for only 65.2 per cent of the total mileage, the latter condition being attributed to the fact that the movement of foreign trucks is generally a long-distance movement, while the average mileage made by Connecticut trucks is lowered by the higher percentage of local hauls.

MOTOR-TRUCK MOVEMENT LARGELY IN SHORT-HAUL ZONES.

Of the tonnage moved by motor truck, 36.9 per cent was hauled from 1 to 9 miles, 30.5 per cent from 10 to 29 miles, and 32.6 per cent 30 miles or more.

Of the motor trucks, 78.6 per cent operate on trips of from 1 to 29 miles and transport 67.4 per cent of the total net tonnage; beyond 29 miles 21.4 per cent of the motor trucks transport 32.6 per cent of the total net tonnage.

One-third of the movement of trucks is an empty movement and two-thirds loaded.

The percentage of loaded vehicles was smallest in the 1 to 9 mile zone, while the percentage loaded remained relatively constant for all hauls from 10 to 70 miles.

Of the total movement of trucks in the State, 62.3 per cent may be classed as regular motor-trucking service providing from one to six or more trips per week.

Of the motor trucks, 80.5 per cent handle 70.5 per cent of the net commodity tonnage in door-to-door delivery; 9.6 per cent handle 14.7 per cent of the tonnage in terminal-to-delivery service, the relatively unimportant balance consisting of terminal-to-terminal and pick-up-to-terminal service.

The 5 to 7½ ton groups of motor trucks carry 34.3 per cent of the total net tonnage, and the ½ to 1½ ton group 26.3 per cent.

Trucks of small capacity lead in the 1 to 9 mile haul, while the percentage of 5 and 7½ ton trucks increases as the haul becomes longer.

Of the tonnage transported over the roads of the State, 81.5 per cent originates in the State.

Of the commodities transported by motor truck in the State, 73.6 per cent may be classified as manufactured articles.

The bulk of motor-truck shipment in Connecticut is of the character of short-haul transportation and does not compete with the business of the railroads.

Of the tonnage, 75 per cent is transported under contract between shippers and truck operators.

The fact that motor-truck rates may be below the level of rail rates constitutes a factor secondary in importance to rapid delivery and trade demands in determining the manufacturer's method of shipment.

The improvement of rail service beyond the 30-mile haul has resulted in a decreased use of motor trucks in the long haul, except for a few specialized commodities.

Actual or potential competition of motor-trucking companies with rail or water services is an incentive to both rail and water operating companies to provide effective transportation.

THE NEED FOR INVESTIGATION OF HIGHWAY TRANSPORTATION.

The foregoing facts are the first conclusions drawn from the survey. The Bureau of Public Roads is convinced that the solution of problems encountered in the highway transportation of freight and passengers depends upon the development of a sufficient volume of similar data in typical sections of the country to provide an authentic basis for analysis, discussion, and an intelligent formation and appraisal of governmental policies. The problems involved are so fundamental and the interests affected so varied and conflicting that impartial and scientific information must be obtained as a basis for a rational solution.

During the past decade the growth of modern State highway systems has increased rapidly, stimulated by the realization of the economic and social values arising from the development of highway systems, the increased economic utility of the motor vehicle, and by the rapid yearly increase of motor-vehicle ownership. The result of this growth is the reemergence of the highway as a factor in the transportation of people and goods.

Trucks of small capacity lead in the 1 to 9 mile haul. Their service does not compete with the railroads. Here are 1½ tons of bananas, and livestock weighing 1¼ tons, each a 9-mile load.

The history of the modern highway is so brief and its growth has been so rapid that there is an amazingly meager body of authentic evidence from which we can measure its economic value or determine its economic sphere of operation as a correlated part of our transportation system.

The literature of the past few years dealing with highway transportation, particularly the transportation of freight, contains a variety of conflicting predictions and conclusions, usually based upon fragmentary or localized data rather than facts.

The highway engineer of to-day is limited on the one hand by lack of revenue for construction and maintenance of highways, and hard pressed on the other hand to maintain adequate highway service for the amazing growth of traffic, and he is critical of traffic elements which, from his point of view, are destructive of the highways or increase the original cost of the investment.

CLAIMS OF INTERESTS CONFLICT.

Some of the promotion literature advocates the increased development of highway intercity transportation of freight without basic evidence as to the comparative economies of operation or an economic knowledge as to whether this new transportation factor should be a supplementary or competitive agency in relation to existing transportation systems, and is usually colored by a desire to create or extend markets for the sale of the instruments of highway transportation.

The increase in the costs of highway construction and maintenance, due largely to the increasing volume of traffic, coupled with the difficulty of raising highway revenue to cover these costs, has directed the attention of State legislatures to the highway transportation of freight and passengers, resulting in an increase of regulatory measures affecting highway transportation.

The rapid development of motor-transport organizations engaged in the transportation of freight during the war period of rail congestion was the real beginning of intercity trucking. This recent expansion of highway freight transportation has directed the attention of the railroad operators to this new, so-called competitor. Particular attention is directed by the railroad management to the taxation of the railroad investment, a portion of this revenue being used for the construction of highways paralleling rail lines, which, it is contended by the rail management, provides a right of way for a competitor.

The enthusiastic promotor of intercity transportation of freight by motor truck insists that the motor truck will relieve the rail lines of an uprofitable short haul of L. C. L. (less-than-carload) freight and reduce operating and terminal charges. As a matter of fact the terminal problem is confined to a limited number of cities and is not applicable to the country as a whole. The rail terminal freight costs of New York City are the exception rather than the rule. The elimination of L. C. L. freight transportation in the short-haul rail zone may be desirable, but it will not necessarily reduce the fixed and operating expenses of rail freight stations already in existence as long as industries in the tributary area continue to originate rail C. L. (carload) freight, and passenger, express, and mail service must be maintained.

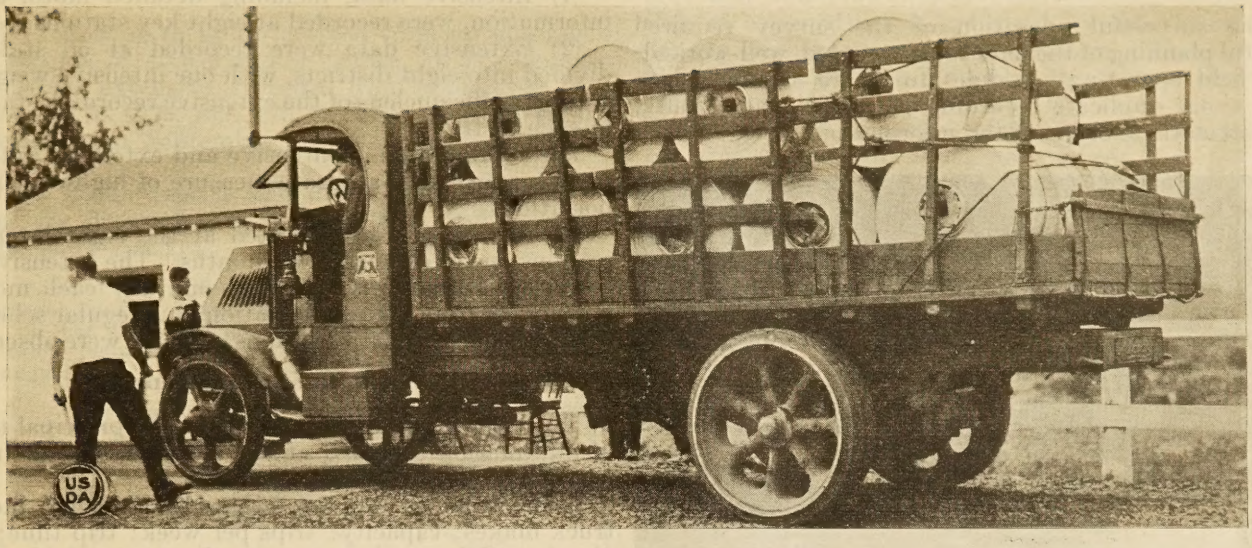
The development of highway transportation has created many difficult problems. The above suggestions are a few of the difficulties, and it is inconceivable that the problems of highway transportation and its relation to other forms of transportation can be answered satisfactorily by theorizing, or that solutions can be accepted as final if based upon individual judgments or fragmentary evidence. The facts of highway transportation in one section of the country are not necessarily applicable to another section unless the industrial and agricultural production as well as the rail and highway facilities are somewhat similar.

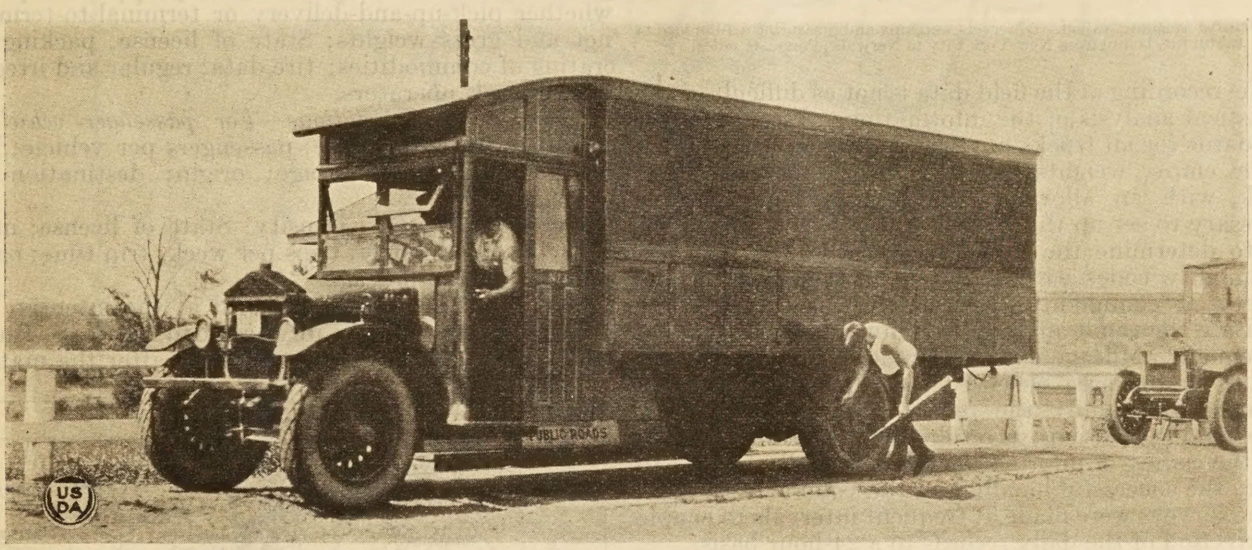
The primary purpose of this research project, which was completed in September, 1923, was to assemble all the salient highway facts necessary to a critical analysis of highway transportation in Connecticut, where the transportation of people and commodities is as highly developed, at the present writing, as in any other section of the country.

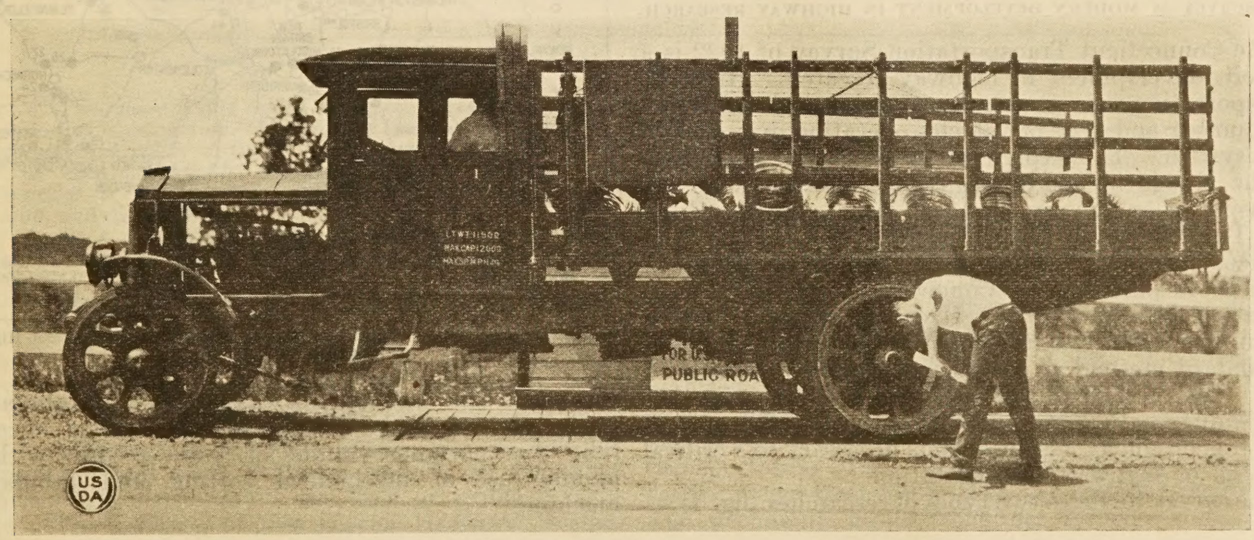
PURPOSES OF THE CONNECTICUT HIGHWAY TRANSPORTATION SURVEY.

The specific purposes which it was hoped to serve by the Connecticut survey were as follows:

1. To serve as an aid in allocating construction and maintenance funds according to the distribution of traffic over the highway system.
2. To predict future traffic.
3. To determine the daily and seasonal traffic density of passenger cars and motor trucks on primary and secondary highways.
4. To determine the seasonal variations in the traffic movement of vehicles, commodities, net and gross loads for trucks of various capacities, commodity and capacity mileage.
5. To measure gross truck loads, net commodity loads, overloads above the capacity of the vehicles, overloads per inch of tire width on the pavement under load, and overloads per inch of tire width channel to channel.
6. To determine the average clearance width of trucks by capacities, and the relation of the width of truck body to truck overloading.
7. To determine the net tonnage movement of freight transported by regular and irregular trucking operators, the net tonnage of freight transported between cities, and the net freight tonnage of products of agriculture, products of animals, products of mines, products of forests, and manufactured products transported between points of origin and destination.
8. To determine the average length of haul of motor-truck shipments by commodities, capacities, and production areas.
9. To determine the type of freight shipment by motor truck—whether a pick-up-and-delivery or terminal-to-terminal movement, and the packing and crating requirements for classes of commodities shipped. The results will indicate for the same commodities any difference in the packing and crating of freight for truck and rail shipment, and the prevailing type of shipment, pick-up-and-delivery or terminal-to-terminal.
10. To gather data concerning the relation of motor transport to other methods of transportation, particularly as to rates, commodity freight classification, schedules of operation, delivery time between points, average commodity mileage, net tonnage, rates, and delivery time in the short, middle-distance, and long-haul zones.
11. To determine the average number of passengers and mileage per vehicle and the percentage of business and nonbusiness movement of passenger cars.
12. To summarize the yearly passenger and commodity traffic over a State highway system, this summarization to serve as the basis of determining the service value of the State highway system for the transportation of passengers and freight.







Manufactured articles form the bulk of the commodities transported by truck in Connecticut. These typical loads consist of 6¼ tons of wire, hauled 26 miles; 6½ tons of typewriters, hauled 113 miles; and 4½ tons of cardboard, hauled 18 miles.

METHOD OF CONDUCTING THE SURVEY.

The successful operation of the survey required careful planning of the data to be recorded, well-worked-out field operating schedules to insure accurate data and avoid duplicate recording of traffic, and, finally, a systematic analysis of the information.

An intensive weighing station. Observers weighing and measuring a 4-ton load of rabbit fur, bound from New York City to Norwalk, Conn., 44 miles.

The recording of the field data is not as difficult as the statistical analysis of the information. Empty-weight standards for all trucks have been evolved, based upon actual empty weights for each make and capacity of truck, with an allowance for body weight. It was necessary to set up these standards before it was possible to determine the net tonnage of loaded vehicles. Commodity codes were required, including all of the variety of commodities transported in the area, to facilitate the rapid analysis of commodity tonnage and movement. Mileage charts between origins and destinations in the area observed had to be computed in advance to simplify the reduction of mileage data. Rules and regulations governing the recording of data and the coding of information were carefully formed to insure the successful handling of the volume of records. Night surveys were made at frequent intervals to enable a correction of the daily records to a 24-hour basis.

THE SURVEY—A MODERN DEVELOPMENT IN HIGHWAY RESEARCH.

The Connecticut Transportation Survey of 1922 is a modern development in highway research. Highway transportation surveys usually record for a brief period the number and type of vehicles operating over a highway system. The experience of the U. S. Bureau of Public Roads in conducting the California Highway Transportation Survey, in 1920, the Tennessee Highway Transportation Survey of 1921–22, and the Connecticut Highway Transportation Survey of 1921 was valuable in planning the Connecticut Highway Transportation Survey of 1922. It can be called a pioneer attempt to determine fundamental facts and is perhaps a standard method of measuring highway transportation. The method will be improved as more researches of a similar nature are undertaken, yet at the present time it is producing essential facts necessary to a critical analysis of highway transportation.

The survey includes two types of researches (fig. 1).

(1) Intensive data, including detailed motor-truck information, were recorded at eight key stations.

(2) Extensive data were recorded at 56 stations, divided into eight districts, with one intensive weighing station as the nucleus of the extensive recording stations in each district.

The combination of intensive and extensive data insures a reasonably accurate measure of highway transportation.

Weight scales were operated at the eight intensive stations one week every two months The extensive recording stations were operated one day each month. By moving from station to station on a regular schedule of operation seasonal variations of traffic were observed.

THE INFORMATION RECORDED.

The following is a brief résumé of the principal types of information recorded at the 8 intensive and the 56 extensive traffic stations.

Intensive traffic stations.—Density of traffic; motor-truck makes; capacity; trips per week; trip time; origin; destination; mileage; commodity; type of shipment, whether pick-up-and-delivery or terminal-to-terminal; net and gross weights; State of license; packing and crating of commodities; tire data; regular and irregular motor-truck operators.

Extensive traffic stations—For passenger vehicles.—Density; State of license; passengers per vehicle; business or nonbusiness usage; origin; destination and mileage.

For motor trucks.—Density; State of license; make; capacity; commodity; trips per week; trip time; origin; destination and mileage.

The data recorded in the field at the intensive and extensive stations were forwarded to the U. S. Bureau of Public Roads at Washington and after the material

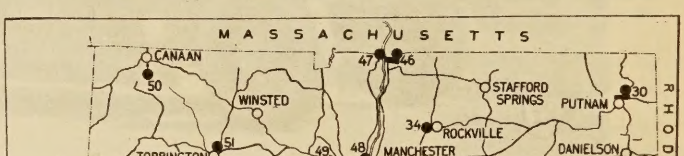


Fig. 1.—Location of extensive and intensive stations in the Connecticut Highway Transportation Survey.

was coded and organized it was punched on tabulating cards. It would be impossible to analyze successfully the enormous volume of traffic records without making use of mechanical sorting and tabulating machines.

DENSITY, SEASONAL VARIATION, AND COMPOSITION OF TRAFFIC.

The following facts are derived from an analysis of the records of 40,613 motor trucks, 16,549 intensive and 24,064 extensive, recorded from September 11 to December 3, 1922, and 175,346 passenger-car records recorded from September 11, 1922, to February 11, 1923.

Daily traffic density and distribution of motor vehicles are illustrated by Figures 2, 3, and 4. These figures show clearly:

1. That the primary highway system in Connecticut carries the bulk of the highway traffic.
2. The major and minor highways and the traffic routes which require the largest outlay for construction and maintenance.

FIG. 2.—Average daily movement of motor trucks and passenger cars on the Connecticut highway system.

3. The major traffic routes which require constant supervision of construction, maintenance, and policing to insure service and safety to traffic.
4. That the greatest density of highway traffic in Connecticut is between large centers of population, production, and distribution.
5. That motor-truck traffic forms a considerably larger proportion of the total traffic on the Boston post road from New Haven, Conn., to New York City, Hartford, and Springfield, Mass., than on the less heavily traveled highways.
6. That at New Haven 15 per cent of the total traffic is made up of motor trucks and 85 per cent of passenger cars, and that at Hartford 10 per cent is made up of motor trucks and 90 per cent of passenger cars.

The percentage of trucks of larger capacity and the average net and gross loads per vehicle on secondary highways are considerably less than on primary highways. The influence of New Haven, Hartford, Bridgeport, and New York City as primary centers of distribution of commodities is indicated by the motor-truck density contiguous to these centers. The type of production in an area influences the volume of motor-truck traffic.

All types of passenger traffic average 2.5 persons per vehicle and 45.1 miles per car per trip. Of this passenger-vehicle movement 35 per cent was for busivess purposes and 65 per cent for nonbusiness purposes. Passengers average 1.7 per car for business usage and 3 for nonbusiness usage, with an average mileage per trip of 29.7 miles for business and 55.5 miles for nonbusiness travel. The real test of business and nonbusiness utilization of a highway system by passenger vehicles is indicated by the fact that 23.5 per cent of the passenger mileage is for business purposes with 76.5 per cent for nonbusiness usage. The passenger usage of the Connecticut highway system is largely a nonbusiness, noncompetitive usage.

OCTOBER—THE MONTH OF MAXIMUM TRAFFIC.

Connecticut motor-truck and passenger traffic varies in volume according to the season as illustrated by Figures 5 and 6. The traffic during the winter months operated under favorable conditions due to the Connecticut highway department's policy of keeping the highways free of snow. Beginning in November a steady decrease in traffic is apparent, reaching the minimum of decline in February, when motor-truck transportation was 40 per cent and passenger-car traffic 70 per cent lower than the October movement. The decline in motor-truck net tonnage during this

FIG. 3.—Average daily movement of motor trucks on the Connecticut highway system. Width of lines indicates density of traffic.

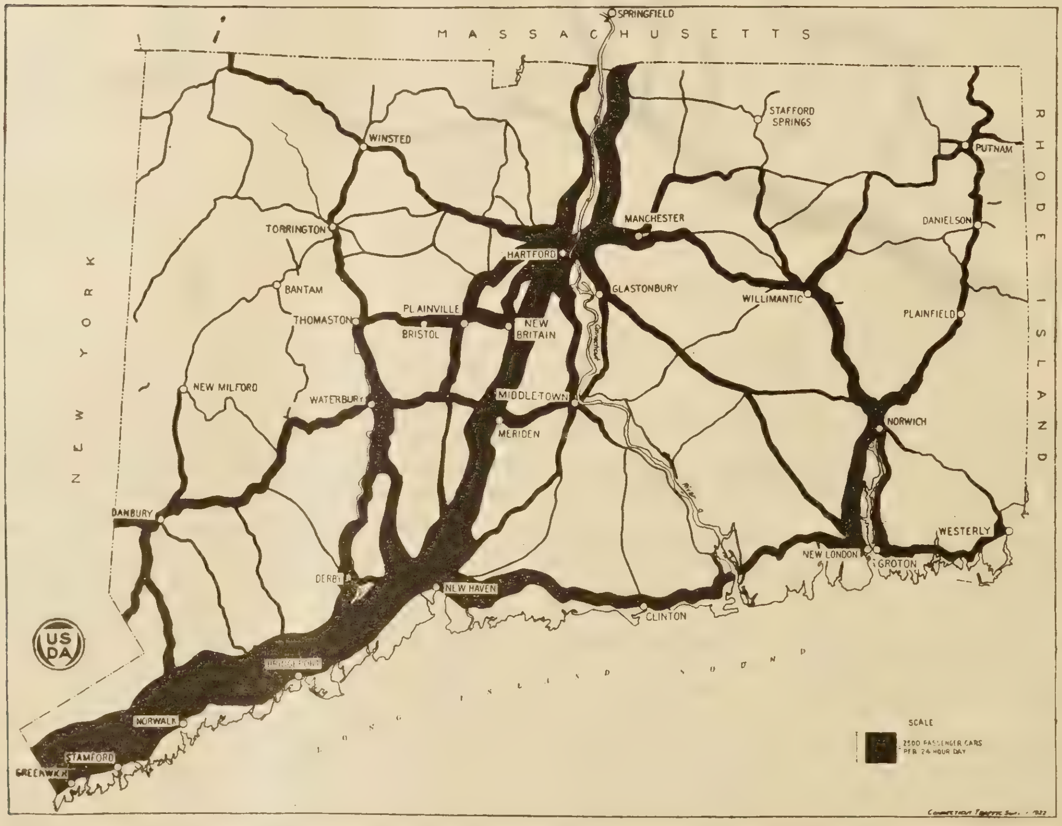


FIG. 4.—Average daily movement of passenger cars on the Connecticut highway system. Width of lines indicates density of traffic.

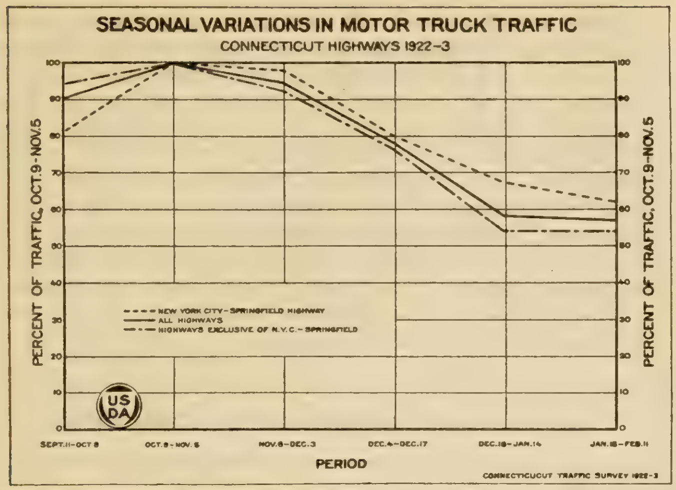


FIG. 5.—Motor-truck transportation in February was 40 per cent lower than in October.

period is partly explained by a decrease in the value of perishable and seasonal commodities shipped by truck during the winter months. The improvement in rail service in this area during the same period resulted in a shifting of a certain percentage of the tonnage from motor-truck back to rail transportation. Motor-truck transportation on secondary highways decreased more rapidly than on the New York City-Springfield, Mass., route, the main interstate highway through Connecticut.

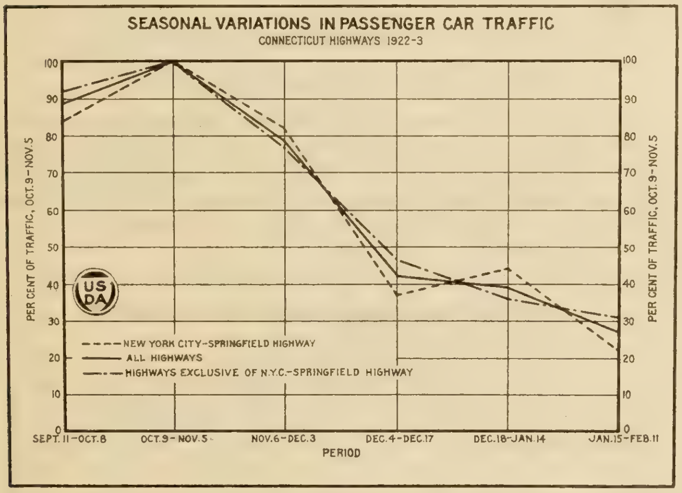


FIG. 6.—The movement of passenger cars was 70 per cent lower in February than in October.

The percentage of trucks of large capacity is smaller on the secondary than on the primary highway system. The decline of motor-truck transportation during the winter months indicates a lack of reliable service which is one of the essentials to the stability of any type of transportation.

Motor-truck traffic, as indicated in Figure 7, begins to increase in volume at 4 a. m., reaching the first traffic peak between 10 a. m. and 12 noon, and the second traffic peak between 2 p. m. and 4 p. m. Motor-truck traffic decreases rapidly after 5 p. m. The night movement from 8 p. m. to 4 a. m. is largely that of the long-distance truck operators transporting special commodities in large-capacity trucks with heavy net loads. The percentage of overloads is considerably larger at night than during the daylight hours.

Comparison of the composition of truck traffic in 1921 and 1922, Figure 8, indicates that the capacity distribution has not changed materially, there being a slight increase in 1922 of ½ to 1½ ton and 5 to 5½ ton capacities and a decrease in the 2, 2½, 3, 4, and 6½ to 7½ ton capacities. Figure 9 shows the prevailing use of the smaller capacities as indicated by the extensive survey, which is representative of traffic on all the highways

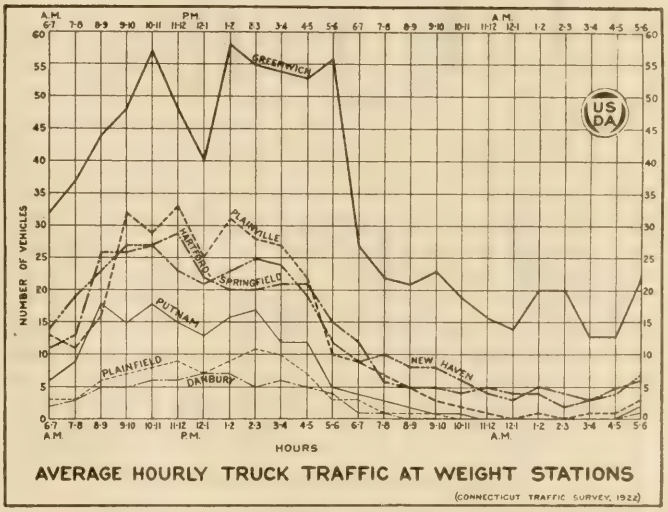


FIG. 7.—Motor-truck traffic is heaviest from 10 a. m. to 6 p. m. The night movement is largely a long-distance movement.

in Connecticut. Both extensive and intensive records indicate the smaller percentage of 6½ to 7½ ton motor trucks operating on the highways.

MOTOR TRUCK OVERLOADING.

Analysis of loaded motor trucks shows that 29.6 per cent are loaded above rated capacity. Motor truck overloading is an uneconomical practice and forces the State to police its highway system constantly to prevent

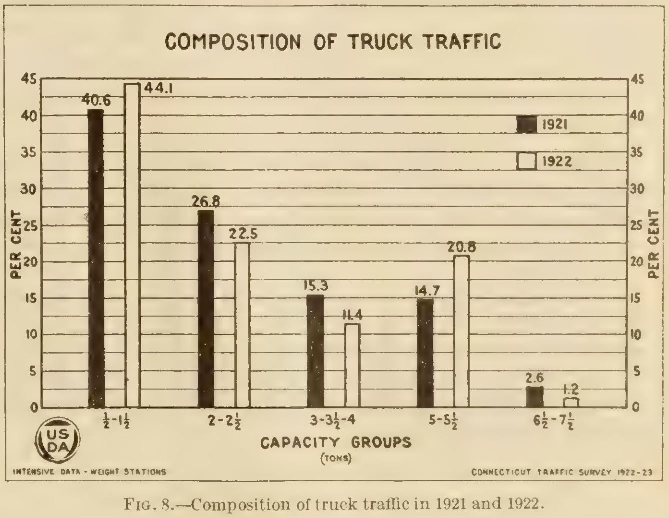


FIG. 8.—Composition of truck traffic in 1921 and 1922.

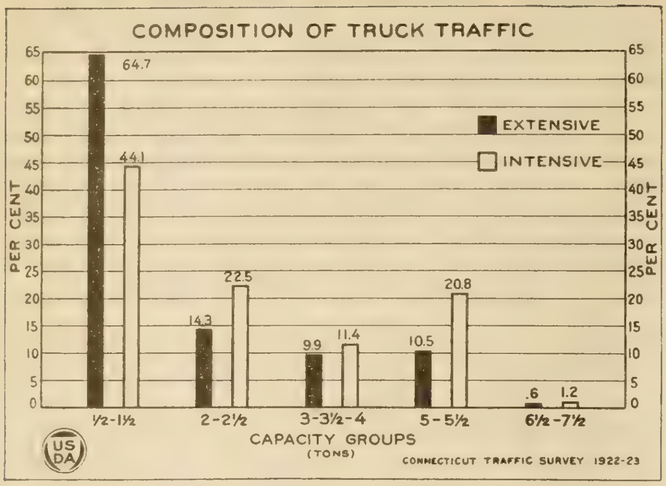


FIG. 9.—Composition of motor-truck traffic by capacity groups.

it. The influence of highway-law enforcement in Connecticut can be seen in Figure 10. The percentage of overloading per capacity in 1922 was considerably lower than in 1921. This decrease was partly due to a realization by motor-truck owners of the rapid depreciation of their vehicles when constantly overloaded, but primarily it was due to police enforcement of the Connecticut laws regulating truck loads.

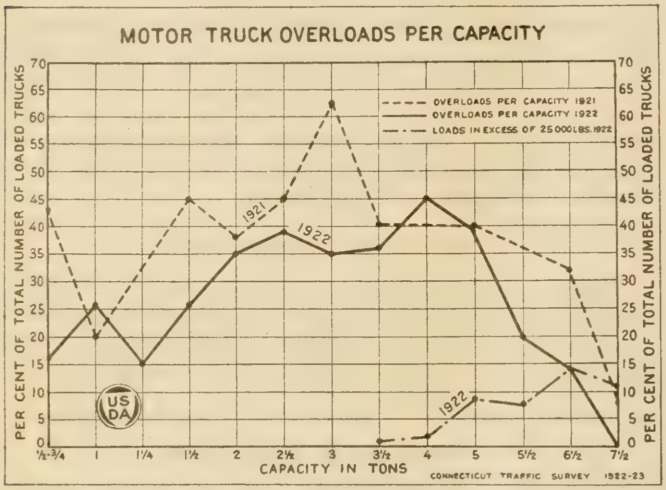


FIG. 10.—The effect of law enforcement is shown by the difference in overloading between 1921 and 1922.

Frequent police inspection and weighing of loaded motor vehicles suspected of being loaded above capacity tends to decrease the practice, especially if the penalty for overloading is sufficient to discourage a repetition of the offense.

Overloading is practiced with all makes and capacities, although the ½ to 1½ ton and 5½ to 7½ ton trucks are not overloaded as regularly as the 2 to 5 ton group. The small percentage of overloads of 6½ to 7½ ton vehicles is partly due to the 25,000-pound maximum gross load limit in Connecticut.

The amount and extent of overloading practiced on Connecticut highways is further illustrated in Figures 11 and 12. Of the total number of overloads 65.2 per cent are 1 ton or less and 34.8 per cent range from 1 to 5 tons per vehicle. Figure 13 clearly indicates that for all capacities an increase in truck body width results in a rapid increase in the percentage of overloads per capacity. Reasonable maximum truck body width and length standards will reduce the practice of overloading. Efficiently organized motor-trucking companies realize the damage to truck equipment when overloaded and regulate their loads to the safe carrying capacity of the trucks.

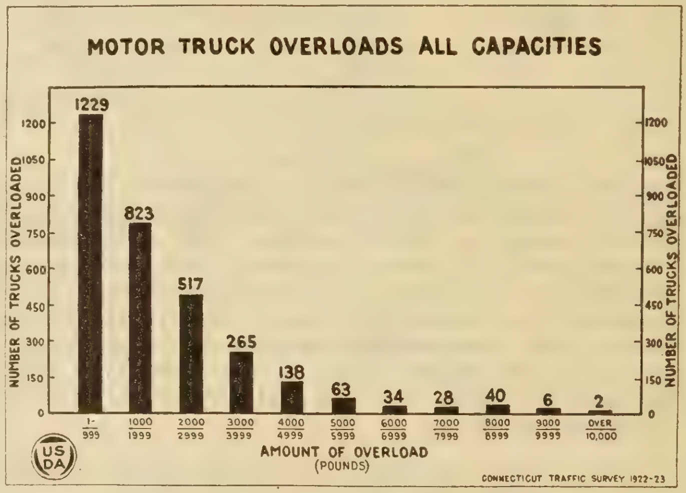


FIG. 11.—The amount and extent of overloading.

MOTOR TRUCK NET WEIGHT AND MILEAGE.

Figure 14 indicates that with an increase in capacity there is an increase in the net load and a rise in the average truck mileage. With the exception of the 5½-ton trucks the average trip mileage of trucks of all capacities is less than 70 miles, indicating that the

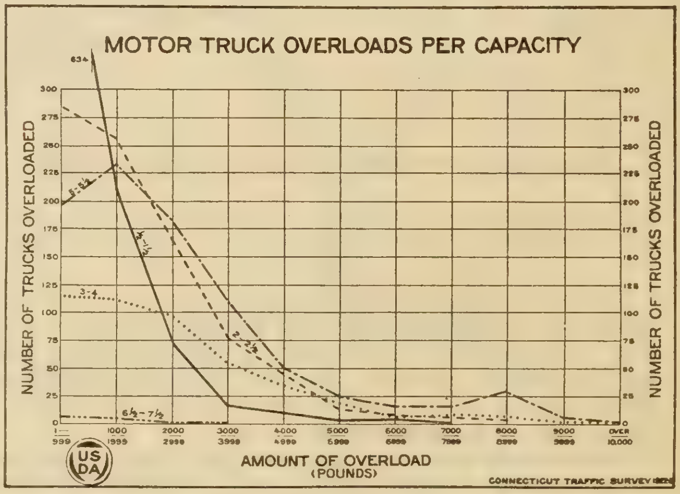


FIG. 12.—The small percentage of overloading of 6½ to 7½ ton vehicles is partly due to the 25,000-pound maximum load limit.

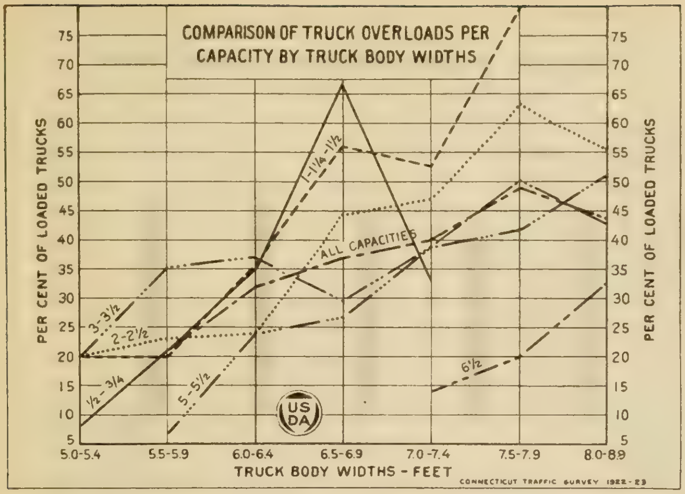


FIG. 13.—The percentage of overloading increases rapidly with increase in body width.

zone of truck transportation, according to the everyday practice of the majority of operators of trucks of all capacities, is less than 70 miles.

The average mileage of pneumatic-tired trucks exceeds the average mileage of solid-tired trucks of all capacities except the ½ to 1½ ton group. (See fig. 15.) The 5 to 7½ ton pneumatic-tired truck mileage is 107.8 miles, while that of the solid-tired trucks of the same capacity group is 61.4 miles. Although the pneumatic-tired truck mileage exceeds the solid-

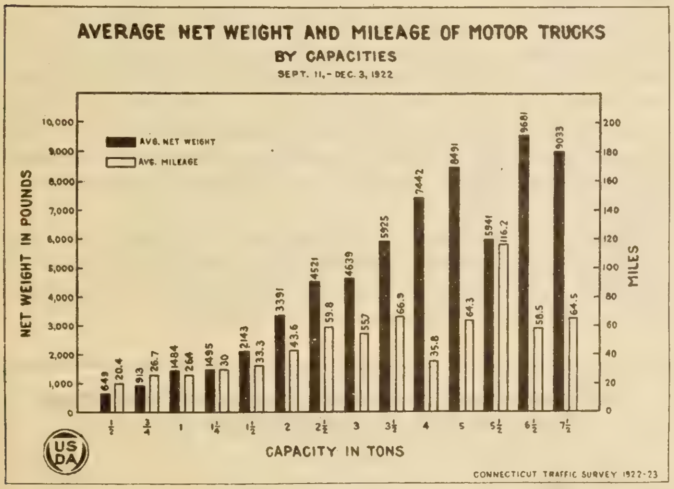


FIG. 14.—Net loads and daily mileage increase with truck capacity.

tired truck mileage, except in the ½ to 1½ ton group, the average net load per vehicle of solid-tired trucks in each capacity class exceeds the average net load of pneumatic-tired vehicles. This is explained by the fact that the present tendency is to use pneumatic-tired trucks for rapid delivery over long distances, transporting commodities of relatively high value and low weight. This type of transportation service is economically justifiable and will remain a permanent part of our transportation system.

Figure 16 illustrates the difference in average mileage of motor trucks from the several States operating on the Connecticut highway system. The average mileage of foreign trucks exceeds the average mileage of Connecticut trucks, partly because they have traveled a considerable mileage before reaching the Connecticut highways. Two tendencies, however, are indicated:

1. The average net loads of foreign trucks exceed those of Connecticut trucks, due largely to the fact that foreign trucks operating over the Connecticut highway system are heavily loaded and of larger capacities.
2. On a ton-mile basis foreign trucks use the Connecticut highway system more per vehicle than Connecticut trucks.

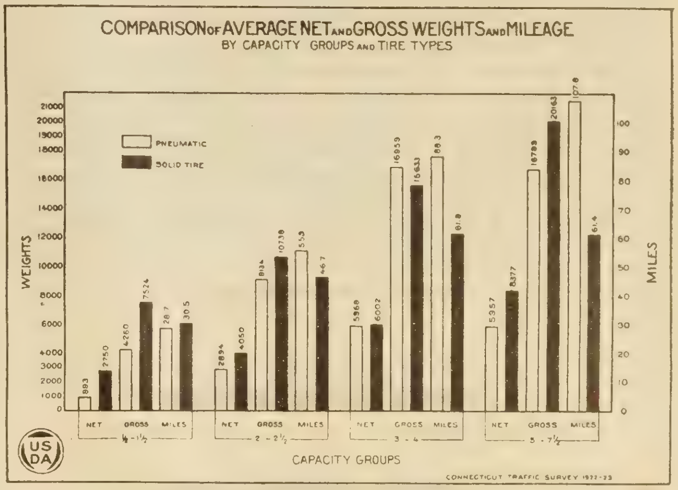


FIG. 15.—Net loads of solid-tired trucks exceed those of pneumatic-tired vehicles, but average mileage of the latter is greater.

CONNECTICUT AND FOREIGN TRUCKS, NET TONS AND MILEAGE.

Figure 17 illustrates the fact that 89 per cent of the motor trucks on the Connecticut highway system are Connecticut trucks transporting 86.5 per cent of the total net tonnage, and 11 per cent are foreign trucks transporting 13.5 per cent of the total net tonnage. Connecticut trucks, 89 per cent of the total vehicles,

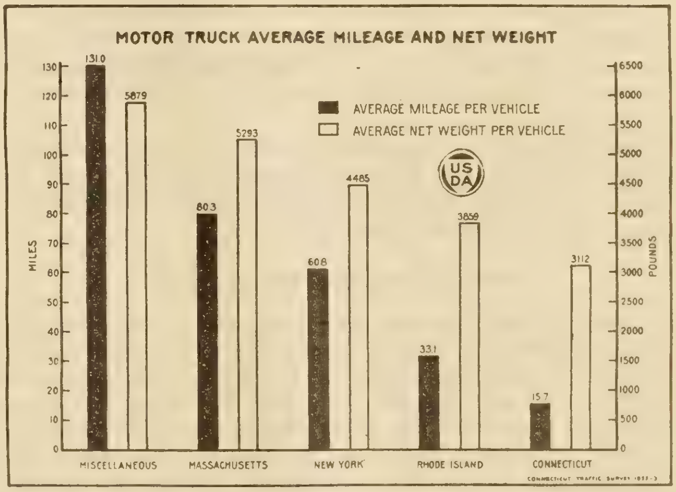


FIG. 16.—Mileage and net weight of trucks from various States.

transport commodities 65.2 per cent of the mileage, while foreign trucks, 11 per cent of the vehicles, transport commodities 34.8 per cent of the mileage.

The explanation of the high percentage of total mileage of foreign trucks is as follows: Mileage figures in Figure 17 are based on origin to destination and include the mileage on all highways—In Connecticut, Massachusetts, New York, Rhode Island, etc. We would expect the Connecticut truck mileage utilization of foreign highways to offset to some extent the foreign truck mileage utilization of Connecticut highways. The foreign truck movement is, as a general rule, a longer-distance traffic, while the Connecticut mileage is lowered considerably by the influence of the Connecticut local hauls.

This analysis, supplemented by a comparison of Connecticut and foreign truck ton-mileage exclusively on the Connecticut highway system, indicates the fact that foreign trucks make a larger ton-mile use of the Connecticut highways than Connecticut trucks.

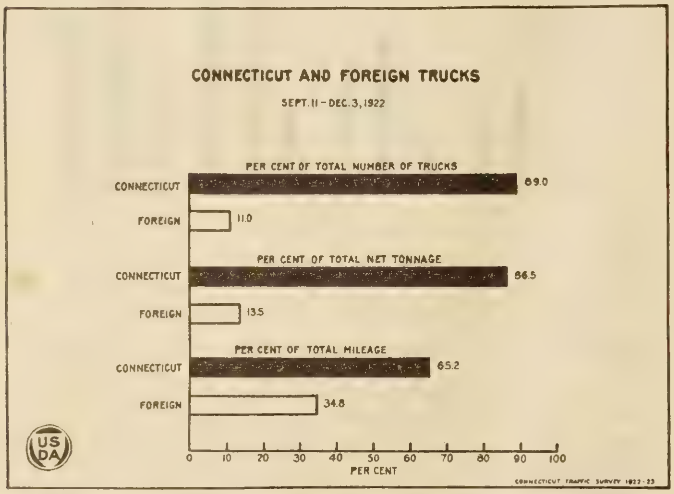


FIG. 17.—Comparison of Connecticut and foreign trucks on basis of number, tonnage, and mileage.

The highways of Connecticut are the logical New England gateways for highway transportation, and naturally foreign trucks use the Connecticut highway system in terms of ton-miles more than do Connecticut trucks.

The practice of operating trucks in Connecticut and licensing the truck in an adjacent State to avoid the higher Connecticut license fee increases the foreign truck usage of the Connecticut highways.

RETURN LOADS AND TRIPS PER WEEK.

One of the difficulties in motor-truck transportation is the problem of return loads. The successful motor-truck operator competing for business must be able to obtain return cargoes or profits decrease. The net rate of return in the motor-truck transportation of freight depends, to a considerable extent, upon the ratio of empty to loaded movement. When the number of motor-truck companies or the number of units offering highway transportation service between two or more points exceeds the needs of shippers of freight the percentage of empty and partially loaded vehicles rises

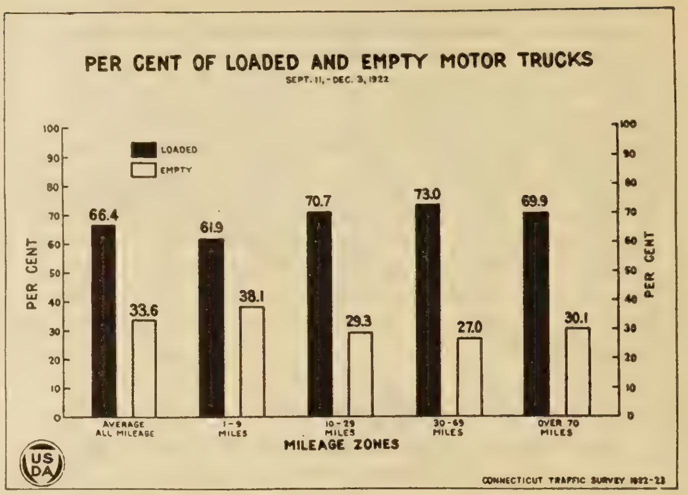


FIG. 18.—Two-thirds of all trucks observed were loaded.

and net profits decrease. The higher the percentage of empty movement the lower will be the rate of return and the keener the competition between truck operators. Figure 18 shows that two-thirds of all motor trucks were loaded, one-third empty. The percentage of loaded vehicles is smallest in the 1 to 9 mile zone, due largely to local distribution, while in the longer hauls, from 10 to 70 miles and over, the percentage of loaded vehicles is approximately the same, ranging from 69.9 per cent to 73 per cent, indicating that the empty factor is relatively constant in both long and short hauls.

The type of production in an area influences the ability of motor truckers to obtain return loads. When manufactured products are shipped by truck and raw materials are shipped in by rail, motor-truck return loads are largely restricted to consumption articles. An extension of the practice of pooling return-load business will increase return loads of motor-truck operators and increase profits.

Figure 19 indicates the number of trips made per week by motor-truck operators and provides a basis for judging the degree of stability of motor-truck service in the highway transportation of freight.

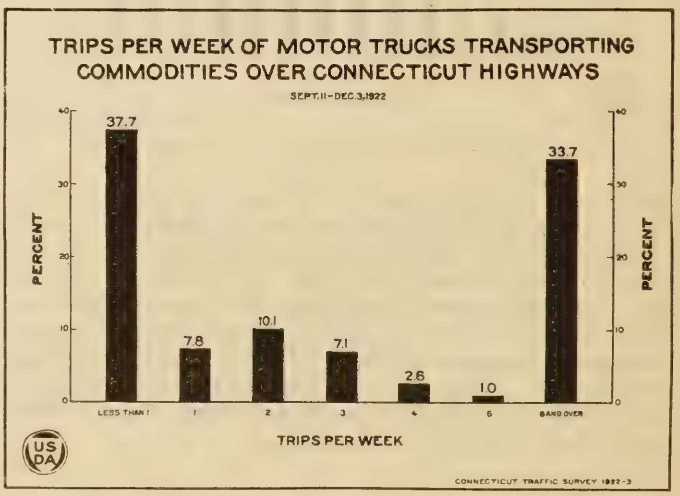


FIG. 19.—The number of trips per week is an indication of the stability of motor-truck service.

Almost two-thirds of the motor-truck movement may be classed as regular trucking service, providing from one to six or more trips each week.

It is interesting to find that 62.3 per cent of the movement can be classed as regular motor-trucking service providing from one to six or more trips per week, while 37.7 per cent is by irregular or intermittent operators making less than one trip weekly.

THE TYPE OF SHIPMENT.

One of the advantages of rural transportation of freight by motor truck is the convenience of pick-up-to-delivery service. Figure 20 shows that 80.5 per cent of the motor trucks handle 70.5 per cent of the net commodity tonnage in door-to-door delivery. Motor-truck transportation from terminal to delivery ranks second in importance, 9.6 per cent of the motor trucks handling 14.7 per cent of the net commodity tonnage. Terminal-to-terminal and pick-up-to-terminal motor-truck freightage are the least important.

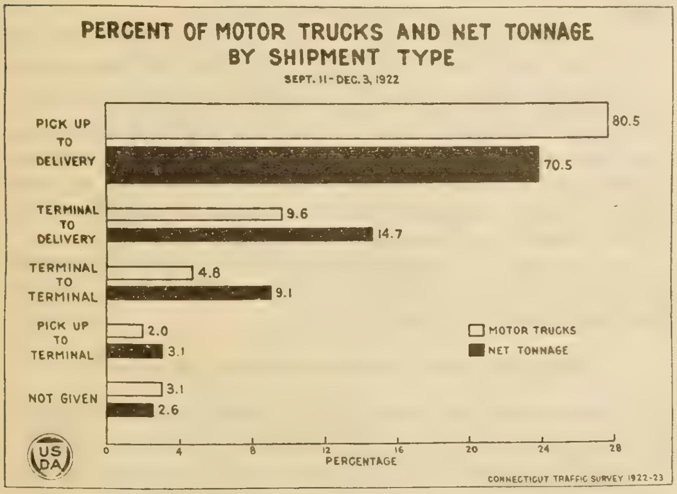


FIG. 20.—Convenient pick-up-to-delivery service is one of the advantages of motor-truck transportation.

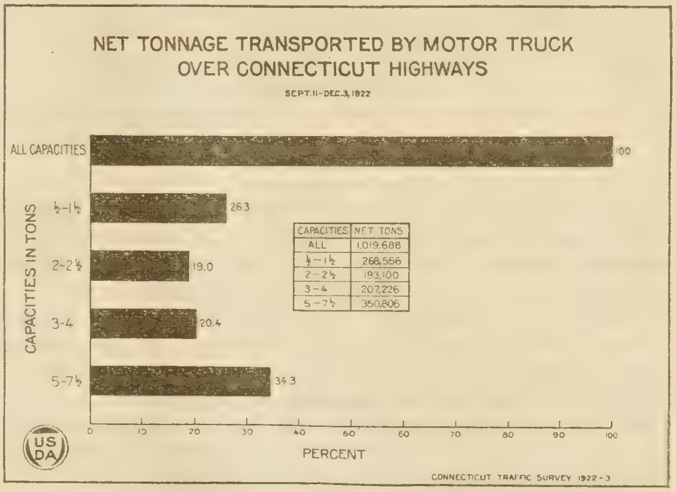


FIG. 21.—Percentage of total net tonnage carried by trucks of several capacity groups.

It can not be said that any particular truck capacity is especially adapted to the motor-truck transportation of freight. Figure 21 indicates that the percentage of net tonnage by motor-truck capacity groups does not vary widely. The 5 to 7½ ton class ranks first in importance, carrying 34.3 per cent of the total net tonnage, and the ½ to 1½ ton group second, with 26.3 per cent of the total net tonnage. The 5 to 7½ ton trucks are used more in the long haul and the ½ to 1½ ton trucks are used more in the local and short haul.

VOLUME OF FREIGHT MOVEMENT BY HIGHWAY.

During the three months from September 11 to December 3, 1922 (tonnage basis 24-hour day), 1,019,688 net tons of commodities were transported over the Connecticut highway system. (Fig. 22.) The competition of motor-truck transportation with rail transportation of freight is not as serious, however, as one would at first believe when told that motor trucks transported 1,019,688 net tons in Connecticut during a three-month period. The condition of railroad transportation in Connecticut was one of the elements responsible for an increase in motor-truck transportation during this period. The lowered efficiency of rail service due to the rail strike beginning July 1, 1922, naturally resulted in an increase in the highway transportation of freight.

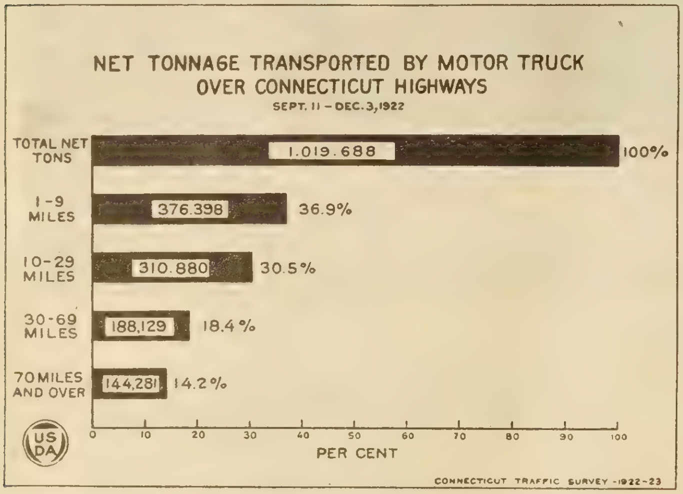


FIG. 22.—Motor-truck traffic in Connecticut divides approximately by thirds into short, middle-distance, and long hauls on the basis of tonnage.

We find that 36.9 per cent of this tonnage was moved from 1 to 9 miles, a local distribution of goods which is noncompetitive. Of this total net tonnage 30.5 per cent was transported from 10 to 29 miles. In this, which may be called the short-haul zone, the tonnage transported is largely noncompetitive. A portion is local distribution from jobbers and wholesalers to retailers. Still another portion is shipped from or to points without rail facilities and by its nature can not be competitive. The balance of the total net tonnage, 32.6 per cent, was transported 30 miles or more. This movement is partially competitive. It is, however, largely a transportation of goods which is not determined by the rate charged for the transportation. Two factors are, in general, responsible for the transportation of these commodities over 29 miles: (1) Lack of efficient rail service enabling shippers to obtain rapid rail transportation of L. C. L. freight; (2) certain types of commodities, such as household goods, wholesale grocery products, meat products, and vegetables, which are especially adapted to motor-truck shipment will probably continue to be shipped by truck for distances beyond the short-haul zone. The total tonnage of these commodities is not very significant.

Figure 23 indicates that 78.6 per cent of the motor trucks are operating from 1 to 29 miles, transporting 67.4 per cent of the total net tonnage. Beyond 29 miles 21.4 per cent of the motor trucks transport 32.6 per cent of the total net tonnage.

Figure 24 shows the relative use of different motor-truck capacities in the local, short, middle-distance, and long-haul transportation of freight by highway.

The small capacities, ½ to 1½ tons, lead in the local 1 to 9 mile zone, decreasing in use with an increase in mileage. The 2 to 2½ and 3 to 4 ton capacities transport approximately the same proportion of tonnage in each of the four mileage zones. The proportion of net tonnage transported by the 5 to 7½ ton capacities increases with mileage from approximately 25 per cent in the 1 to 9 mile zone to 50 per cent in the haulage over 69 miles.

Figure 25 indicates the percentage of motor trucks of various capacities in each mileage zone. The percentage of ½ to 1½ ton capacities decreases with increase in mileage, while the percentage of 2 to 2½, 3 to 4, and 5 to 7½ ton capacities, with but a slight deviation, increases with increased mileage. The large capacities are more generally used in the longer hauls. This is shown by the fact that 66.2 per cent of the motor vehicles transporting commodities from 1 to 9 miles have capacities of ½ to 1½ tons and 7 per cent have 5 to 7½ ton capacities, while 17.4 per cent of the motor vehicles transporting commodities 70 miles or over have ½ to 1½ ton capacities and 38.6 per cent have 5 to 7½ ton capacities.

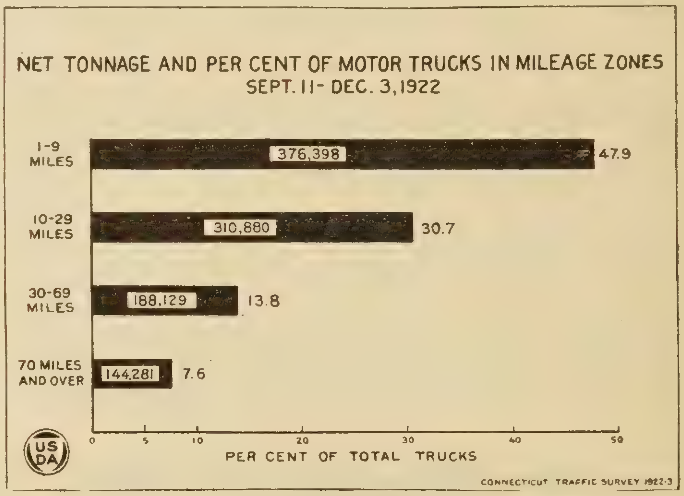


FIG. 23.—The smaller trucks ply in the short and middle-distance zones; the larger trucks take the long haul.

Figure 26 shows clearly that the bulk of the commodities (81.5 per cent) transported over Connecticut highways originates in the State of Connecticut, and 18.5 per cent originates in New York, Massachusetts, Rhode Island, and miscellaneous States.

On the whole the majority of the highway services of the Connecticut highway system are for Connecticut producers and consumers.

BULK OF TRAFFIC IN MANUFACTURED ARTICLES.

Motor-truck transportation of goods in New England is largely limited to the movement of finished or semi-finished manufactured products as illustrated in Figures 27 and 28. It is natural in an industrial area that a larger proportion of the goods transported by motor

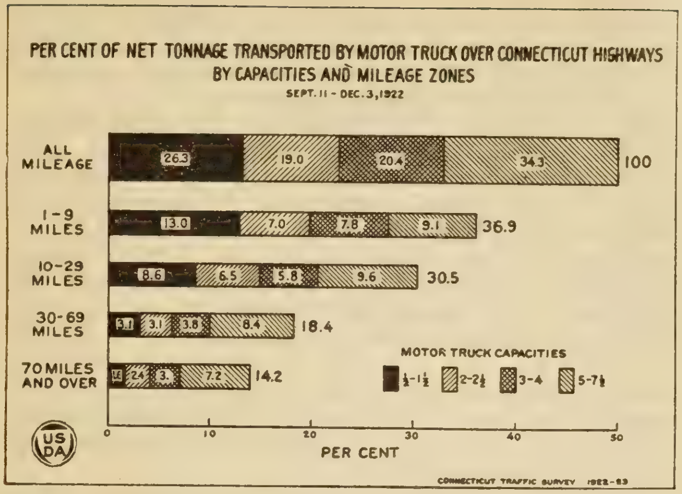


FIG. 24.—Percentage of tonnage carried by trucks of various capacities in several mileage zones.

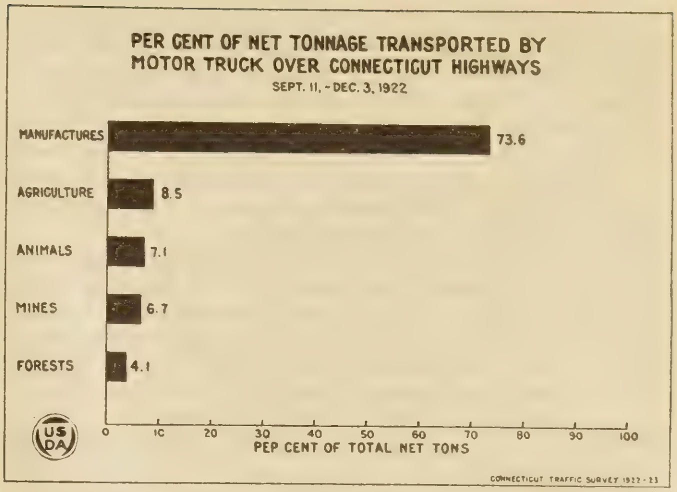


FIG. 27.—Manufactured commodities are transported in greatest volume.

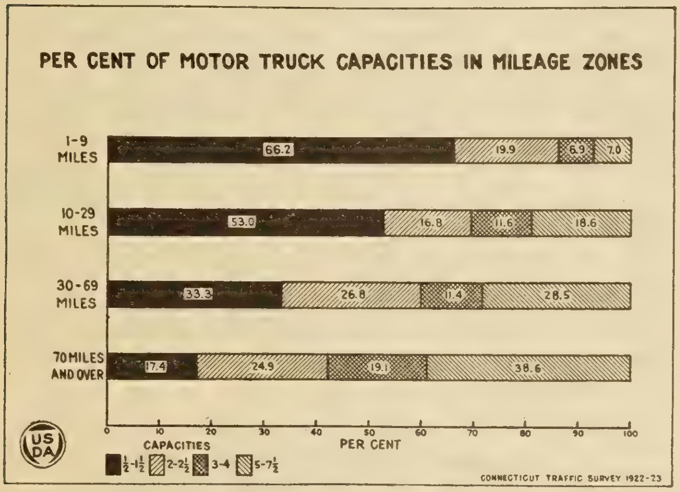


FIG. 25.—Truck capacities used in several mileage zones.

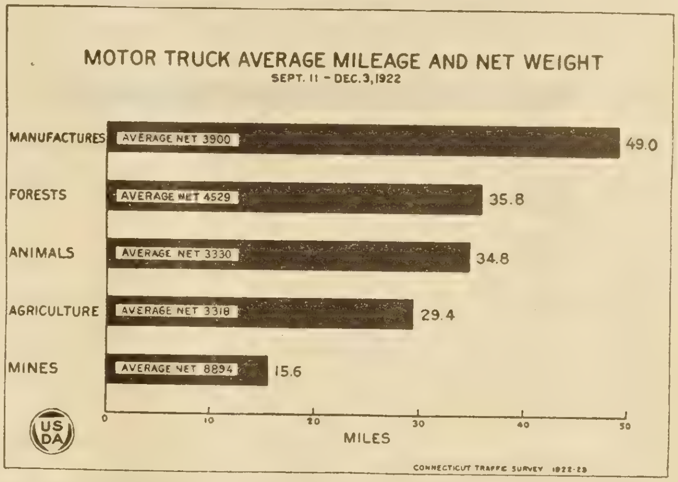


FIG. 28.—The average haul of manufactured commodities is greater than that of other commodities.

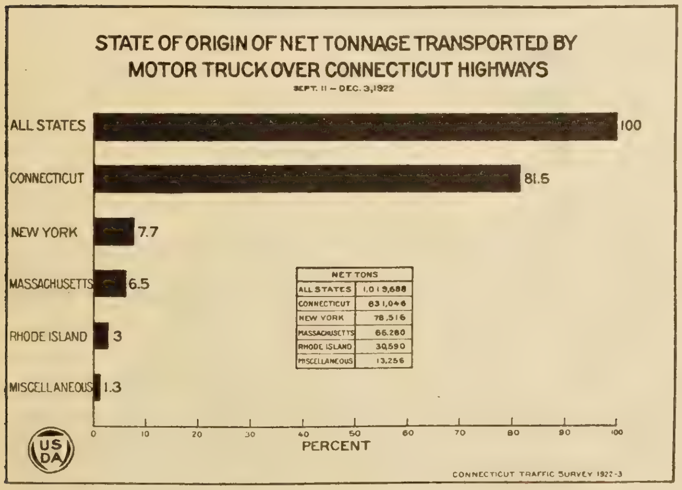


FIG. 26.—The bulk of commodities transported originates in Connecticut.

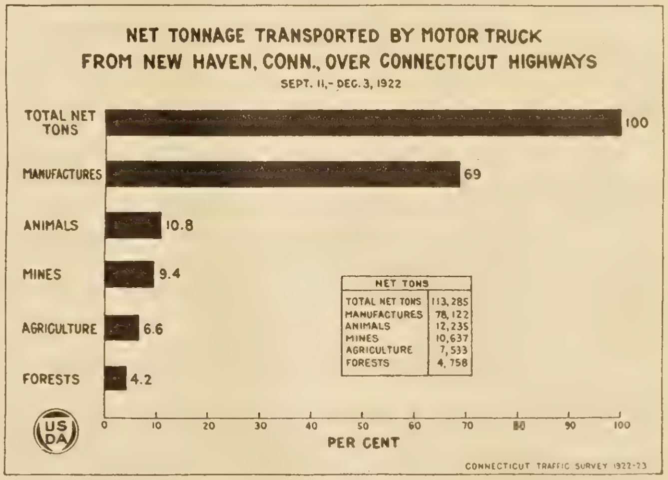


FIG. 29.—New Haven ranks first in origination of highway tonnage.

truck would be manufactured products. There is, however, a more pertinent explanation of the fact that 73.6 per cent of the commodities transported over the highways of this State are manufactured articles. Manufactured commodities are usually of small bulk and high value. The margin of profit in highway transportation of freight of this character is considerably larger than in the transportation of the heavy and bulky products of forests and mines.

Analysis of the origin and destination of motor-truck freight between cities and areas in New England indicates a tendency of outgoing and incoming net tonnage to balance. The small cities as a rule receive more truck freight than they originate, largely consumption goods. More motor-truck freight is shipped out of large centers of population than is received. This is largely due to a concentration of manufacturing near centers of population and the assembly of rail freight at larger centers for redistribution to smaller communities.

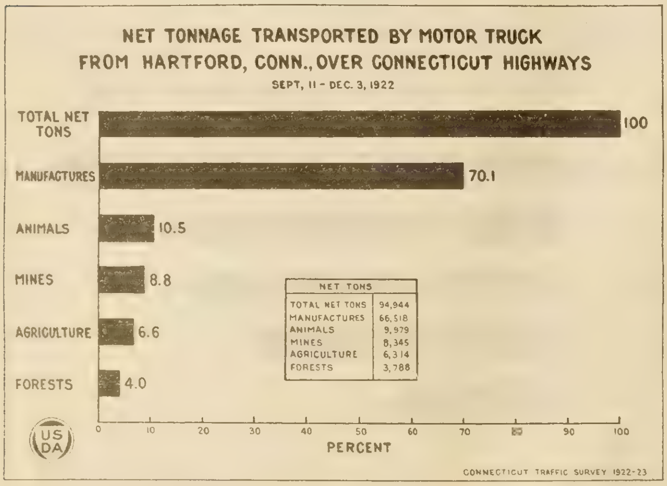


FIG. 30.—Hartford ranks second in origination of highway tonnage.

New Haven ranks first, Figure 29; Hartford second, Figure 30; and New York City third, Figure 31, in the origination of net tonnage transported by motor trucks over Connecticut highways. It is to be noted that the New Haven and Hartford percentage of tonnage for each commodity class is approximately the same, indicating that from cities of this size approximately the same ratio of commodity tonnage will be distributed by motor truck.

The influence of New York City as a motor-truck distribution center for products of agriculture and animals is indicated by the fact that while products of animals rank second and products of agriculture fourth for New Haven and Hartford, products of agriculture are second and products of animals third in importance for New York City.

THE MAJOR FIELDS OF MOTOR-TRUCK TRANSPORTATION.

A brief preliminary statement of the four main fields of operation for motor trucks in the transportation of freight is made in the order of their importance, based largely upon the results of the Connecticut Highway Transportation Survey supplemented by a study of motor-transport organization, operation, rates, and competition in the New England area.

1. Organized urban motor-truck transportation in congested rail and steamship terminal areas consisting of motor truck terminal-to-terminal freight transfers as well as pick-up-and-delivery service.

The congestion of incoming and outbound freight will be reduced, freight cars will be unloaded more rapidly and will be more efficiently utilized in the line haul of freight, and consignors and consignees of freight will receive better service. This is well illustrated by the operation of the United States Trucking Co. in New York City cooperating with the Erie Railroad in transferring freight by motor truck from the Erie, New Jersey, terminal to New York City for delivery. The success of organized terminal trucking depends upon the formation of terminal trucking companies with an organization large enough to handle efficiently the volume of business and guarantee satisfactory service.

Carefully organized and efficiently operated terminal trucking companies, assured of the cooperation of the rail and steamship operators, will materially speed up the terminal movement of freight, decrease the volume of freight warehoused, reduce the cost of moving freight through terminals, and, above all, lower the rail delivery time of L. C. L. freight. Such a cooperative arrangement will result in rapid terminal-to-terminal transfers and pick-up-to-delivery freight service, at least in the larger cities, guarantee a reasonable profit to the terminal motor-trucking company and expedite the movement of freight in congested areas. The organization of one large urban motor trucking company, or affiliation of a limited number of large trucking companies, will stabilize the motor-trucking business, permit the making of uniform rates, insure a fair return, eliminate the irregular "cut-throat" operator, and tend to reduce street congestion in terminal areas.

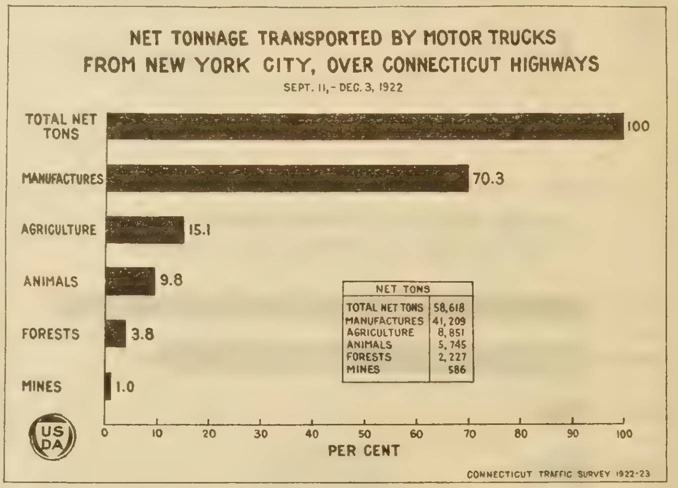


FIG. 31.—New York City ranks third in origination of highway tonnage in Connecticut.

2. The organization of motor-truck freight service supplementing existing rail and water transportation systems. The development of motor-trucking companies in areas inadequately served with rail or water transportation offers an enormous possibility for the economic extension of highway transportation. This service is especially desirable in the economic development of new areas or localities with insufficient trans-

portation facilities and will make available additional tonnage for movement by rail or water. This is a noncompetitive service, extending and supplementing existing rail and water transportation.

3. The short-haul transportation of freight in the New England area, approximately 30 miles. Transportation by motor truck in this zone is largely noncompetitive, consisting mainly of the assembly and distribution of goods.

The short-haul zone in one area is not necessarily applicable to another area. The distances between cities and areas of production and distribution, the type of prevailing production as well as the character of rail or water transportation may decrease or increase the above zone of the short haul.

4. Truck transportation of special commodities in the long-haul zone in which delivery time, the character of the goods transported, or demands of the industry or trade indicate the desirability of motor-truck transportation. This type of freight is but a small percentage of the total net tonnage transported by motor truck.

MOTOR-TRUCK MOVEMENT LARGELY NONCOMPETITIVE.

In general, the analysis of motor-truck transportation in the New England area indicates that the bulk of the shipment, considered on a tonnage basis, is a noncompetitive, short-haul transportation of freight. From the manufacturers' point of view, "with a permanent improvement in rail service a considerable portion of the long-haul motor-truck freight will be shipped by rail." Motor trucking at present is loosely organized, keenly competitive, operating largely on a contract basis, with rapid fluctuation in rates and with a gradual development of larger motor-trucking companies which will ultimately insure stability of service and rates. A difficult problem is met in applying the principle of government regulation of common carriers to motor-truck companies engaged in the transportation of freight in New England. At the present time approximately 75 per cent of the motor-truck tonnage is transported under contract agreements between the shippers and motor-truck operators. These contracts, oral or written, fix the rate per hundred pounds of freight for definite periods, and the rates may vary for each individual shipper. The regulation by governmental agencies of motor-truck transportation of freight under agreements of this nature may be open to doubt. This question, however, has not been finally passed upon by the courts and until it is so decided there can be no authoritative determination of it. Motor-truck operating companies are compelled to operate largely under the contract system on account of the destructive competition of competing motor-truck companies. It is entirely probable that with the development of governmental regulation of motor-truck transportation, with the resulting stabilization of the motor-truck rate structure and publication of rates, the majority of motor-trucking companies now operating in New England will discontinue the contract system. Motor-truck operators, according to their own statements, "would welcome reasonable regulation which will insure stability of rates and eliminate the 'cut-throat' competition" which now prevails in the New England area.

One of the outstanding developments of the present era of motor-truck transportation in New England is the sharp competition existing between interurban motor-truck operators. They do not operate on the basis of published tariffs since rates fluctuate rapidly, largely due to the underbidding of small motor-trucking organizations and irregular operators. There is a lack of uniformity as to the basis of motor-truck rate making. Rail rates, mileage, tonnage available, "what the traffic will bear," contracts, bid business, and the probability of return loads are the principal factors in rate making. The return-load business is an important factor in rate making, and as a general practice in New England the rates charged for return loads are lower than rates for outbound freight on the theory that a small profit on the return trip is more profitable than to return empty. The result of this practice is to lower the level of rates charged for outbound business. For example, motor-truck companies operating out of New York City to New Haven, Conn., are forced to meet the competition on their outbound New York-New Haven trip of the lower rates of the New Haven motor trucks returning from New York City. The New Haven operators on outbound loads to New York City must meet the return-trip rates of the New York City trucks returning from New Haven. The result is that the practice of lower rates for return-trip cargoes forces down the rates on outbound loads and the trend is for rates to be influenced largely by the lowest return-load rates charged which tend to approach the cost of operation.

MANUFACTURERS PREFER TO HIRE TRUCKS.

The relatively high percentage of failure, or withdrawal from business, of the smaller trucking companies indicates a narrow margin of profit. Business depression or a decrease in the volume of freight available for truck transportation results in intense competition for business, lowered rates, and a transfer of trucking companies to other fields.

As a general rule manufacturers find it unprofitable to own trucks for L. C. L. transportation, preferring to hire local trucking companies, usually on a contract basis. A combined motor truck and boat, and motor truck and rail L. C. L. transportation service is developing in the New England territory. The Starin-New Haven Boat Line transports freight from Hartford, Meriden, Middletown, New Britain, Wallingford, and Waterbury, Conn., to New Haven by motor truck and by boat from New Haven to New York City. Freight is shipped on the basis of joint or through rates. The same type of service on a smaller scale is offered by the Hanson Steamship Co. from Norwalk, Conn., to New York City, and the North & East River Steamship Co. from Stamford, Conn. to New York City.

The development of combined motor-truck and water service is a practicable possibility in the northeast territory in view of the fact that the majority of the industrial cities are situated within a maximum distance of 40 miles from available water-shipping points. Combined truck and water transportation between Connecticut points and New York City provides an overnight movement of freight as well as a pick-up-and-delivery service outside of port towns.

COMBINED MOTOR-TRUCK AND RAIL SERVICE DEVELOPING.

A correlation of motor-truck and rail service is developing similar to joint motor-truck and water transportation of freight. The service performed by Stone's Motor Truck Express is typical of this development. Freight is assembled by motor truck in eastern New England territory tributary to Providence, Pawtucket, and Woonsocket, R. I., and Boston, Lynn, Salem, Peabody, Cambridge, Worcester, Fitchburg, Leomister, Brockton, and Haverhill, Mass. Freight in this area is transported by motor truck to selected rail shipping points and the long haul is handled by the New York, New Haven & Hartford Railroad. On an average, 10 carloads of freight are shipped daily from this territory by Stone's Express to New York City. Stone's Express ship freight according to the above methods in territory tributary to Philadelphia, Pa., Baltimore, Md., Washington, D. C., Camden, N. J., and the Eastern Shore of Maryland, in cooperation with the Pennsylvania Railroad.

The Boston & Springfield Despatch Trucking Co. offer a combined motor-truck and rail service between Boston and Springfield, Mass., in cooperation with the Boston & Albany Railroad. The New York & New England Despatch Motor Truck Co. operate combined motor-truck and rail freight service between New York City and Springfield, Mass., in cooperation with the New York Central and Boston & Albany Railroads.

This modern correlation of highway transportation with rail and water agencies for the movement of freight is an economic function of motor transportation and offers an extensive field for development, supplementing and extending the facilities of rail and water service. It is not competitive, provides a pick-up-and-delivery service, allocates the short haul to motor transportation and the long haul to rail or water, and provides rapid transportation of L. C. L. freight from consignor to consignee, which is the aim of effective transportation.

REASONS GIVEN FOR MOTOR-TRUCK SHIPMENT.

Generally, manufacturers in New England ship by motor truck for two principal reasons:

(1) *Reliable and prompt service.*—Motor-truck delivery to a given destination is rapid and the consignment is certain to arrive on time. This is particularly true of consignments from inland points to docks for boat transportation.

(2) *Trade demands.*—The retail trade, appreciating the economy of maintaining a smaller stock of goods with a smaller outlay of invested capital and fresh goods, insist upon motor-truck delivery daily or often enough to replenish their supply.

The fact that motor-truck rates may be below the level of rail rates constitutes a factor secondary in importance to rapid delivery and trade demands in determining the manufacturers' method of shipping.

The additional cost of rail transportation, due to packing and crating charges and weight of packing and crating, is not an important factor in the manufacturers' choice of motor-truck transportation. As a general rule only a small proportion of the net tonnage transported in New England by motor truck is packed or crated materially different for rail or truck movement.

The volume of products shipped by New England manufacturers by motor truck is small compared with their rail L. C. L. and C. L. tonnage. The attitude of the majority of manufacturers can be summed up as follows: "If service becomes efficient and rapid the most of our freight will be shipped by rail." A lower truck rate per 100 pounds is not the determining factor. It is largely a question of service time. Certain types of commodities are especially adapted to motor-truck transportation. In the majority of cases the character of the commodity, the volume regularly available for shipment, and the service offered determine the method of transportation.

Railroad freight congestion and rail embargoes force manufacturers to ship goods by motor truck in both the long and short haul. Rail embargoes result in an immediate increase in the net tonnage of freight transported over the Connecticut highway system.

The improvement of rail service in New England, particularly beyond the 30-mile haul, has resulted in a decrease in the use of motor-truck transportation in the long haul, except for a few specialized commodities in which trade considerations or the nature of the commodities make it desirable to use motor-truck transportation. Actual or potential competition of motor-trucking companies with rail or water service in the transportation of freight is an incentive to both rail and water operating companies to provide effective transportation.

Highway transportation is an integral part of our transportation system and the facts obtained from the Connecticut Highway Transportation Survey clearly illustrate that in making a comprehensive study of the transportation problems of the country it is essential to obtain a sufficient volume of highway traffic data in different areas to evaluate scientifically the economic services that highway systems produce in cooperation with rail and water agencies in the transportation of people and commodities.

THE FLOW OF WATER THROUGH PIPE CULVERTS.

COOPERATIVE TESTS BY THE U. S. BUREAU OF PUBLIC ROADS AND THE STATE UNIVERSITY OF IOWA.

A COMPARISON OF CONCRETE, VITRIFIED CLAY, AND CORRUGATED METAL PIPES.

By D. L. Yarnell, Senior Drainage Engineer, U. S. Bureau of Public Roads; and Sherman S. Woodward, Professor, and Floyd A. Nagler, Associate Professor, Department of Mechanics and Hydraulics, State University of Iowa.

A SERIES of tests, designed to supply greatly needed data on the flow of water through short pipes such as culverts, particularly of the larger diameters, has been made during the past year by engineers of the Bureau of Public Roads and the State University of Iowa under a cooperative arrangement entered into by the two agencies.[1]

The results, it is believed, will be of considerable general interest and may embody useful suggestions for the highway engineer.

Three facts stand out from the results of the tests as worthy of the most serious consideration of highway engineers.

The first is that highway engineers must pay more attention to the coefficient of roughness of the material forming the culvert. So long as the different materials used for culvert pipe did not differ greatly in roughness and hence in their frictional resistance to moving water, engineers were perhaps justified in not giving this factor much consideration. But in recent years a new material, corrugated metal, has been extensively manufactured into culvert pipe. Pipes made of this material are shown by these tests to offer much greater frictional resistance to the flow of water than other materials used, such as vitrified clay, cast iron, concrete, and timber. While for pipes of each material the coefficient of roughness in the Kutter formula is found to increase with increase in the size of pipe, the tests show that, for all sizes it is nearly twice as great for corrugated metal pipe as for concrete and vitrified clay pipe.

The second fact brought out clearly by the tests is that the quantity of water a culvert will discharge is directly proportional to the square root of the head and bears no relation to the grade at which the pipe is laid, if the pipe flows full, as it should at maximum capacity. The water in a pipe culvert under these conditions does not act as does that flowing in an open ditch where the quantity of discharge is dependent upon the slope or grade of the water surface in the ditch, but, as is the case with any pipe flowing full, the discharge depends upon the water pressure available to force the water through the opening and the pipe. In the case of a culvert the water pressure which causes discharge is that furnished by the difference between the water level at entrance and outlet. The depth of submergence has no effect on the discharge so long as the difference of the water levels at the two ends of the culvert remains the same.

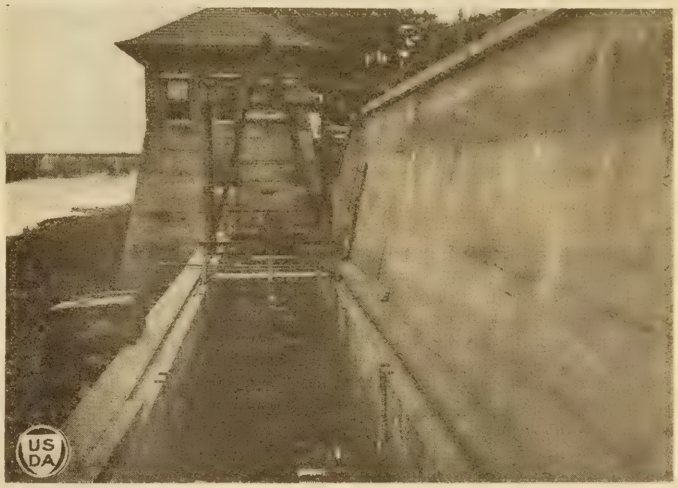


Fig. 1.—Hydraulic laboratory looking downstream toward laboratory building. Testing canal with 24-inch corrugated metal pipe in place. Platform on left supports stilling well and hook gauge for obtaining head on the weir.

The third outstanding observation is that the head loss at the culvert entrance is an important factor in determining the discharge and varies greatly with the type of entrance used. The data on the effect of different types of entrance on the entrance loss are among the most interesting of the findings from the tests.

For a square-cornered entrance the average entrance loss coefficient is found to be 0.393. Textbooks on hydraulics give the coefficient for a square-cornered entrance as 0.50.

METHODS OF REDUCING ENTRANCE LOSS.

The beveled lip of concrete pipe, shown in Figure 5, assists greatly in reducing the entrance loss at a straight end wall entrance, the average entrance loss coefficient for all sizes and lengths being 0.099.

A vitrified clay pipe culvert with the same form of straight end wall is especially efficient by virtue of the shape of the bell end of the pipe, shown in Figure 6. The average entrance loss coefficient for the clay pipe bell is 0.063. By taking care to make a gradually rounded entrance, this entrance loss can always be reduced practically to zero. When the bell is filled with concrete shaped in the form of an ellipse, the coefficient becomes 0.020.

Although the entrance loss is greater for a corrugated metal pipe, the reinforced rounded end of the metal pipe greatly assists in reducing the amount of entrance loss. The average entrance loss coefficient for the corrugated metal pipe is 0.226.

[1] The experiments were conducted by D. L. Yarnell, senior drainage engineer, U. S. Bureau of Public Roads, and Floyd A. Nagler, associate professor of mechanics and hydraulics, State University of Iowa, under the direction of S. H. McCrory, chief of the division of agricultural engineering, U. S. Bureau of Public Roads. Sherman M. Woodward, professor of mechanics and hydraulics, State University of Iowa, acted as consulting engineer for the investigations, making suggestions in the conduct of the experiments and collaborating in the preparation of the data and the report.

The tests on the vitrified clay and corrugated metal pipe, comprising 1,139 separate experiments, were run from Aug. 22 to Nov. 4, 1922. The tests on the concrete pipe, 341 in all, were run from Apr. 20 to May 29, 1923.

A. F. Fisher, highway engineer of Johnson County, Iowa, furnished the corrugated metal pipe used. The concrete and vitrified clay pipe were purchased by the U. S. Bureau of Public Roads.

Special conical entrances tested did not prove as efficient as the bell end of a clay pipe in reducing the entrance loss, although they assist greatly in reducing the entrance loss into a corrugated metal pipe. The average entrance loss coefficient for the various conical entrances used in connection with vitrified clay pipe is 0.088 whereas for the clay pipe bell this coefficient is 0.063. The average entrance loss coefficient for the various conical entrances used in connection with corrugated metal pipe is 0.044, whereas for the regular end of a metal pipe this coefficient is 0.226. There is little difference in the effectiveness of the various types of conical entrances in reducing the entrance loss.

The standard commercial vitrified clay pipe increasers when used as entrances are not as effective in reducing the entrance loss as the regular bell end of a clay pipe. The average entrance loss coefficient for the standard commercial vitrified clay pipe increasers is 0.142, whereas for the regular bell of a vitrified clay pipe this coefficient is 0.063.

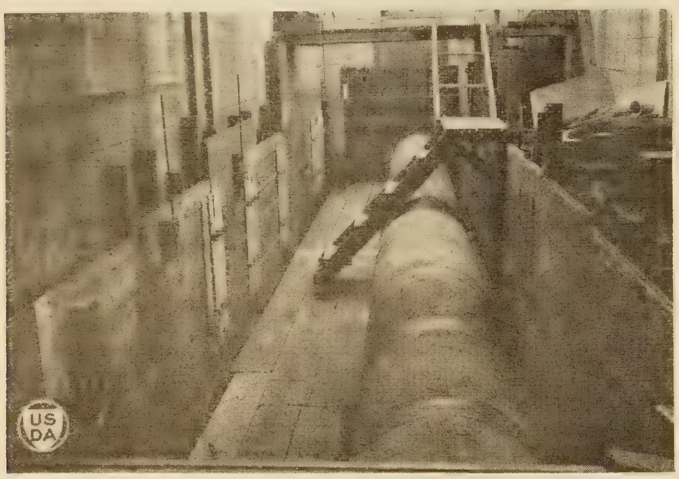


FIG. 2.—24-inch concrete pipe in place for testing.

The tests of a 45° wing wall used in connection with a corrugated metal pipe culvert show that it has a slightly beneficial effect in reducing the entrance loss below that resulting from the use of the straight end wall. The average entrance loss coefficient for these wings used with corrugated metal pipe culverts is 0.221. The efficiency of these wings in increasing the discharge in a metal pipe over that obtained with the straight end wall will be seen by comparing the discharge equations in Table 3.

A vitrified clay pipe culvert used with a 45° wing wall actually shows a greater entrance loss and a lesser discharge than the same pipe with the straight end wall. The average entrance loss coefficient for these wings used in connection with the clay pipe is 0.114, whereas for the straight end wall it is 0.063.

U-type wings are relatively inefficient compared with a straight end wall in reducing the entrance loss in vitrified clay pipe. The wings increase the entrance loss and consequently decrease the discharge of the culvert. The average entrance loss coefficient for the U-type wings is 0.197 compared with 0.063 obtained for clay pipe with the straight end wall.

Apparently for the concrete pipe it makes very little difference in the entrance loss whether the pipe projects 3 inches, 2 feet, or 4 feet beyond the head wall. When the 12-inch concrete pipe with a square corner projected 3 inches beyond the head wall, the entrance loss coefficient was 0.354; with a 2-foot projection the entrance loss coefficient was 0.342; and with a 4-foot projection, the entrance loss coefficient was 0.361. However, for a 4-foot projection of 12-inch concrete pipe with beveled lip entrance, the entrance loss coefficient was only 0.092.

For 18-inch corrugated metal pipe with a 3-inch projection the entrance loss coefficient was 0.314, while for the same pipe with 2-foot and 4-foot projections the entrance loss coefficients were about 0.55.

The carrying capacity of vitrified clay pipe culvert with a straight end wall may be increased somewhat by filling the bell with cement mortar, rounding the mortar so as to form an elliptical entrance.

The discharge of any pipe culvert having a square-cornered entrance may be increased by setting the pipe back a few inches from the face of the head wall and rounding the concrete in the head wall next to the circumference of the pipe.

While it is recognized that practical considerations will dictate how far the hydraulic principles involved in these results can be followed, the application of the first set of results, namely, those showing the coefficient of roughness of the several types of pipe used for highway culverts, is both direct and obvious.

DISCHARGE A FUNCTION OF SQUARE ROOT OF HEAD FOR FULL CULVERT.

The conclusion that the discharge of a culvert is proportional to the square root of the head and bears no relation to the grade at which the pipe is laid is of course based upon the assumption that the culvert is designed to flow full, an assumption which probably departs from the prevalent practice, but it is believed that there are sound reasons for altering present methods of design in this particular.

If highway culverts are so designed and installed that they are only partially filled at times of great run-off, one naturally asks just how deep should a culvert be filled to discharge the water for which it is designed? This depth might form the basis for a "capacity" rating for comparing different types of culverts. On the other hand, if a culvert under such conditions discharges only partially full, is there not great lack of economy in the design which gives a larger waterway than necessary? After considerations such as these the writers concluded that the normal basis for comparing culverts should be established upon the pipe flowing full, giving its maximum capacity with a given "head." It is certain that most pipe culverts, even 18 or 24 inches in diameter, although installed to drain only a small area, may at some time be taxed to their full capacity. For instance, a run-off of 1 inch in 20 minutes from 2 acres of land will entirely submerge an 18-inch pipe at the inlet. It seems only logical, therefore, that the full culvert should be the capacity basis for design. However, the comparisons which have been made in this report apply without modification to culverts flowing half full or any fraction of full depth.

It is recognized that an obstacle to the design of culverts as pipes flowing full is presented in the inclination of highway engineers to keep the culvert high and near the road surface in order to reduce the quantity of ditching at the outlet end. The writers believe that sometimes this procedure reduces the discharging capacity of the culvert below what might easily be obtained by merely lowering the culvert at slight expense under favorable conditions. They can see no danger in installing a culvert so that it will flow full if possible. The "head" or pressure involved is not as dangerous as it might seem. Flowing under a "head" is intended to mean merely flowing full, not flowing under any excessive head.

The statement that the discharge bears no relation to the grade at which the pipe is laid under the conditions assumed implies no objection on the part of the writers to the laying of culverts on slight grades. Culverts are laid on a slope in order that they may clear themselves of sediment during normal flow. This is a matter that has not been under investigation in these tests and hence is not emphasized. But it is the desire of the authors to emphasize that it is not *necessary* to lay a culvert on a slope to develop maximum capacity, i. e., flowing full; in fact, it is quite doubtful if the practice of laying the culvert on a grade has all the merits claimed for it. Certainly in flat country the culvert grade does not determine the velocity of flow but rather the difference in elevation of the water at the upstream and downstream ends. Even when flowing partially full, the water surface will find the grade it needs for flow through the culvert irrespective of the slope of the bottom of the culvert.

If the culvert is installed on a steep grade the chances that it will flow full and hence discharge at maximum capacity are greatly reduced. The writers have performed experiments which demonstrate that the slope is not very great at which the discharge capacity of a culvert, even with the inlet end submerged, will be considerably less for a given difference in water surface upstream and downstream than for the same culvert built at a flatter grade.

The question has been raised as to whether the significance of the nature of the entrance would be as great in the case of pipes flowing less than full as in the experiments with pipes flowing full under head. It has been suggested that under the conditions normally obtaining in pipe culvert installations the width of the approach ditch is greater than the diameter of the pipe and that these conditions might result in the formation of eddies which would vitiate the effect of the rounded pipe entrance. It is possible to settle whatever doubt there may be on this score. Experiments have been made with culverts flowing partially full and it has been demonstrated that the nature of the entrance is fully as significant as when the pipe flows full, if not more so. The experimental channel was itself several times wider than the culverts and experimental results when eddies were formed could not be distinguished from those obtained when the water above the culvert seemed perfectly quiet.

PREVIOUS EXPERIMENTS AND METHODS OF DESIGN.

Nearly 30 different formulas have been proposed for use in determining the run-off and waterways required for culverts. In practically all of these formulas the area of the waterway is given direct. Apparently no consideration has been given to the coefficient of roughness in the culvert pipe. Although it might appear that, since the amount of run-off as determined is only

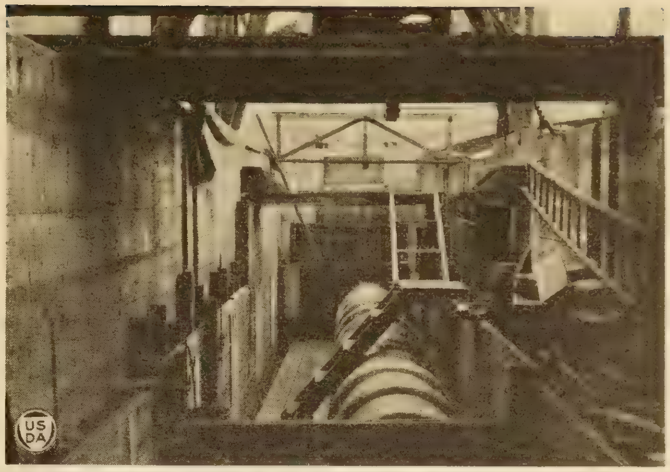


FIG. 3.—30-inch vitrified clay pipe in place for testing.

an approximation, there is no necessity for considering the roughness factor in the culvert; yet the great variation in this factor for culverts of various materials would seem to warrant some consideration of this coefficient. Most formulas contain a variable whose value depends upon the topography of the watershed tributary to the proposed culvert.

Of the various highway departments and railroads, apparently only the Pennsylvania Railroad engineers [2] use the well-known Kutter formula for determining the required area of waterway. They compute the volume of water reaching the site of the proposed culvert in a given time by the Burkli-Ziegler formula.

This formula is

$$q = cr\sqrt{\frac{s}{a}}$$

in which q = the water reaching the culvert in cubic feet per second per acre.
r = the average cubic feet of rainfall per second per acre during heaviest rainfall.
s = the general grade of the drainage area in feet per thousand.
a = the area drained in acres.
c = a coefficient. For average areas, c equals 0.625.

Gilman and Chamberlain [3] state that the Burkli-Ziegler formula was brought to this country by Rudolph Hering in 1881.

The formula most commonly used for computing the velocity of flow in open channels and pipes is

$$V = C\sqrt{Rs}$$

in which V = velocity in feet per second.
R = mean hydraulic radius, or cross-sectional area of flow divided by wetted perimeter, in feet.
s = the grade or slope in feet per foot of length.
C = a coefficient.

[2] "Determining Sizes of Culverts," O. L. Grover, Public Roads, Vol. 1, No. 12, April, 1918, p. 39.

[3] "The Principal Formulas Proposed for Determining Run-Off and Waterways for Culverts," Engineering Contracting, Vol. XXV, Mar. 29, 1911, p. 366.

This formula was first proposed by a French engineer, Chezy, in 1775. Universal experience shows that the coefficient C varies with the hydraulic radius, the slope, and the amount of frictional resistance offered by the walls of the pipe. The measure of this frictional resistance is commonly called the coefficient of roughness or the roughness factor. Ganguillet and Kutter, two Swiss engineers, in 1869 derived an expression for computing the coefficient C in Chezy's formula based upon experimental data in open channels. Their formula takes into consideration the effect of the slope, the coefficient of roughness, and the hydraulic radius. This formula is so complicated that it is seldom used directly in hydraulic computations. Instead, diagrams and tables based on the formula are used almost exclusively by practicing engineers to obtain numerical results corresponding to the formula. Although numerous other formulas have been proposed, probably the great majority of engineers in English-speaking countries still use Kutter's formula.

Engineers heretofore have not considered the coefficient of roughness in pipes or conduits of short lengths to be of much importance. This, as has been stated already, was perhaps natural and justifiable so long as the different materials used for culvert pipe did not differ greatly in roughness and hence in their frictional resistance to moving water. In recent years, however, corrugated metal has come into extensive use for culvert pipe, forming a conduit whose surface obviously causes a greater frictional resistance to the flow of water than the other materials used, such as vitrified clay, cast iron, concrete, and timber.

Many tests have been made to determine the coefficient of roughness of concrete and vitrified clay pipes as well as pipes of other materials, but comparatively few have been conducted on corrugated metal pipe. Probably the first tests [4] on the flow of water in corrugated metal pipe were made by Cone, Trimble, and Jones in 1913. These tests were made on a semicircular metal flume having an arc length of 132 inches and a lineal length of 1,745 feet. The coefficient of roughness "N" for use in Kutter's formula varied from 0.0196 to 0.027, depending upon whether the tests were made on a tangent or a curve.

In 1917, the division of drainage investigations, Bureau of Public Roads, U. S. Department of Agriculture, conducted a series of experiments on the flow of water in two sizes of corrugated metal pipe, 8 and 10 inches in diameter. The length of pipe tested was 200 feet. The coefficient of roughness "N" obtained for the pipe flowing full ranged from 0.017 to 0.021. A synopsis of these tests was published in [5] Engineering News-Record.

SCOPE OF THE INVESTIGATION.

In order to determine accurately the effect of friction on the flow of water in short pipes, a total of 1,480 tests were made on concrete, vitrified clay, and corrugated metal pipe culverts flowing partly full and full, both with a free and submerged outlet. The sizes tested of each kind were 12, 18, 24, and 30 inches in diameter. To determine the effect of the length of the culvert on the flow, the 24-inch pipe of the three kinds of material was tested in three lengths, namely, 24, 30, and 36 feet. The other sizes were tested in the 30-foot length only.

[4] "Frictional Resistance in Artificial Waterways," by V. M. Cone, R. E. Trimble, and P. S. Jones, Colorado Agricultural Experimental Station Bulletin No. 194, 1914, p. 9.

[5] "The Coefficient of Roughness in Corrugated Iron Pipe," D. L. Yarnell, Engineering News-Record, vol. 88, Mar. 2, 1922, p. 352.

It has been demonstrated that in pipes of short length the loss of head at the entrance of the pipe is an important factor. Whereas many tests have been made on small orifices acting under both low and high heads, few tests have been made on large circular vertical orifices acting under low heads. In culverts this latter condition prevails. For the purpose of studying the effect of various types of entrance in reducing the entrance loss several types of entrance were used. These included all of the standard types approved by the U. S. Bureau of Public Roads which consist of the straight end headwall, wing walls set at 45° to the pipe line, and the U-type wing. The effect of varying the height of the wing wall was also tested. In addition to these entrances a study was made of the flow through pipe culverts constructed without any head walls. This was accomplished by projecting the entrance end of the pipe for some distance through the headwall.

The maximum range of head obtained on the culverts for the different sizes tested varied from 1.05 feet on the 30-inch clay pipe to 3.29 feet on the 12-inch clay pipe.

DESCRIPTION OF EXPERIMENTAL PLANT.

The hydraulic laboratory of the State University of Iowa [6] is located on the west bank of the Iowa River, south of the university dam. The laboratory, built in 1919, consists of three main parts—the testing canal, the basin, and the tailrace. For this investigation only the testing canal was used. This canal (fig. 1), built of concrete, is 130 feet long, 10 feet wide, and 10 feet deep. At the upstream end and connected with the dam is a wooden gate 10 feet wide by 12 feet deep. This gate is regulated by a hand-operated hoist. Just below the gate, in the wall next to the river, a wooden sluice gate, 5 feet wide by 4 feet high, is provided for the purpose of flushing out silt which may collect above the dam near the intake. Recesses were built in the walls of the canal at intervals of 25 feet for use in building wooden bulkheads when needed in experimental work. Every 10 feet along the canal and 1 foot above its bottom, 2-inch pipes were placed transversely through the east wall for the attachment of piezometer tubes. At the lower end of the testing canal another 5 by 4 foot wooden sluice gate is set in the east wall. The floor of the testing canal has a grade of 0.20 per cent sloping to the south.

THE WEIRS.

For use in measuring the amount of water flowing through the pipes, a sharp-crested rectangular weir of the suppressed type was constructed. The length of the weir crest used in the experiments on the 24 and 30 inch pipe was 10 feet. Since, for the smaller pipe, it was necessary to obtain smaller quantities of water than could be measured on the 10-foot weir using the lowest head consistent with accuracy, a false wall was constructed upstream from the weir bulkhead for a distance of 36 feet, thus making possible the use of a weir with a crest of 5 feet.

The weir plate was so placed that the nappe of the weir cut free and was fully aerated by means of the recesses in the walls of the flume at each end of the crest.

[6] "State University of Iowa's New Hydraulic Laboratory," by Stuart Sims, Engineering News-Record, vol. 85, July 15, 1920, p. 124.

The quantity of water passing over the weir was regulated by raising or lowering the headgate at the upper end of the canal. Several baffles were built in the canal in order to insure that the water, entering the canal with much turbulence, would pass over the weir in a smooth condition and with a fairly uniform velocity distribution.

To determine the discharge over the weir, Bazin's formula was used in all computations. This formula is:

$$Q=\left[0.405+\frac{0.00984}{H}\right]\left[1+0.55\left(\frac{H}{p+H}\right)^2\right]b\sqrt{2g}\;H^{\frac{3}{2}}$$

in which Q = discharge in cubic feet per second.
H = head in feet on the weir.
b = length in feet of crest.
p = height in feet of weir crest above the bottom of the flume.
g = acceleration of gravity = 32.16 feet per second.

The quantity in the first bracket represents a coefficient and the quantity in the second bracket is the correction for the velocity of approach to the weir.

A bear-trap weir, 4 feet high and located 18 feet downstream from the outlet of the 36-foot culvert, was used to obtain a submerged outlet for the pipe. This weir was hung on hinges and was regulated by means of a block and tackle attached to a windlass which was mounted on a platform built over the canal.

HOOK GAUGES.

Five hook gauges were used in conducting the investigation. These were of the all-metal Gurley type with a 45° point.

Hook gauge No. 1 was located on the east side of the canal 15.77 feet from the weir. The gauge was bolted to a heavy block which was securely fastened to the outer side of the concrete wall of the canal. A 1½-inch pipe connected the opening in the wall of the canal, 10¾ inches above the bottom, to a 15 by 36 inch cylindrical galvanized stilling tank placed immediately under the hook gauge. This opening corresponded quite closely to that used by Bazin in his noted weir experiments; Bazin's opening was 16.35 feet from the weir and 6 inches above the floor of the canal.

Hook gauge No. 2 was located near the upper end of the pipe line being tested. This gauge was used to obtain the elevation of the surface of the water in the canal at the entrance to the pipe. The gauge was bolted to a block which was secured to the west wall of the canal. A 1½-inch pipe led from the opening in the bulkhead of the culvert being tested to another galvanized stilling well placed directly under the gauge.

Hook gauge No. 3 was placed near the bulkhead to the outlet of the 24-foot length of pipe. It was mounted in a manner similar to gauge No. 2. This gauge was installed to measure the water level in the canal at the outlet.

Hook gauge No. 4 was located at the outlet of the 30-foot pipe.

Hook gauge No. 5 was located at the outlet of the 36-foot pipe.

PIEZOMETERS AND PIEZOMETER TUBES.

In order to measure the depth of flow in the culvert when flowing partly full, as well as to secure the hydraulic gradient when the outlet of the pipe was submerged, glass piezometer tubes fastened to enameled staff gauges were placed on the side of the canal and connected to the underside of the culvert pipe as described below.

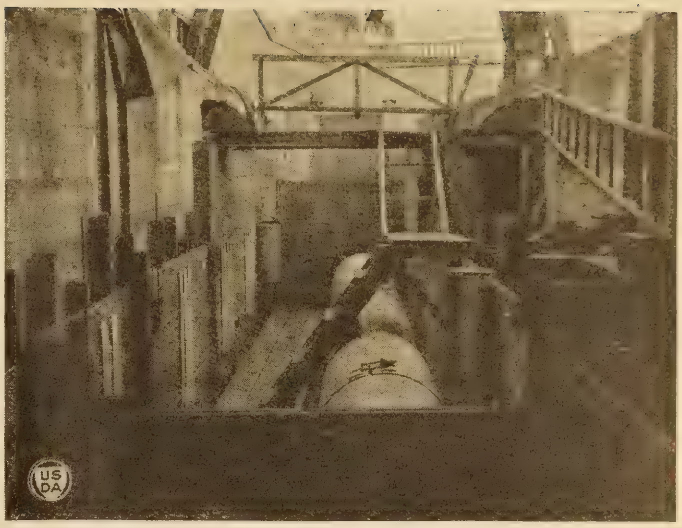


FIG. 4.—30-inch corrugated metal pipe in place for testing.

At the mid-point of each joint of vitrified clay pipe a small hole was drilled through its wall and a ¼-inch iron nipple, 3½ inches long, was inserted, care being taken that the tube did not project inside the tile bore. This tube was set in cement and any unevenness on the inside wall of the pipe at the entrance of the tube was removed by coating the surface with a little cement. The piezometer connections in the concrete pipe were made in a similar manner.

In making the piezometer connections in the corrugated metal pipe spacings were used which conformed as nearly as possible to those of the concrete and clay pipe. Holes were drilled in the surface of the outer corrugation on the outside of the pipe and ¼-inch iron nipples, 3½ inches long, were inserted through these holes until the nipples were flush with the inside bore of the pipe. The space in the corrugation around the nipple inside the pipe was filled with solder, thus forming a plane surface of some extent on all sides of the orifice. This type of piezometer connection was considered best for obtaining the pressure of the water in corrugated metal pipe after experiments on several types of piezometer connections in this kind of pipe.

The culvert pipe were placed so as to have the tubes about 8 inches above the inside bottom of the pipe. Connections were made by rubber tubing to 1-inch glass tubes 3 feet long attached to white enameled gauge staffs secured to the side of the canal. These gauge staffs, 3.3 feet long, were graduated with divisions of 0.02 foot, and the markings were such that they could be easily read with little chance of error. With glass tubes of 1-inch bore, the effect of capillarity is negligible and need not be considered.

LAYING THE PIPE.

The pipes were laid level with water-tight joints on a wooden floor in the bottom of the testing canal. (See figs. 2, 3, and 4.) Tight wooden bulkheads were installed at each end of the pipe line, so that the pipe could remain exposed in the dry while running full of water even with both ends submerged to a considerable depth. The entrance to the culvert pipe was located 26.8 feet downstream from the weir. Two baffles were placed in the canal upstream from the pipe in order to avoid commotion of the water as it entered the pipe.

The joints of the concrete pipe were made water-tight with cement mortar.

The joints of the vitrified clay pipe were made water-tight as follows: From two to three strands of oakum were placed in the bell around the circumference of the pipe and tightly tamped. The remaining space was then filled with cement mortar, which was packed in the bell. It was necessary to allow the mortar to set overnight to obtain sufficient strength to resist the pressure of the water.

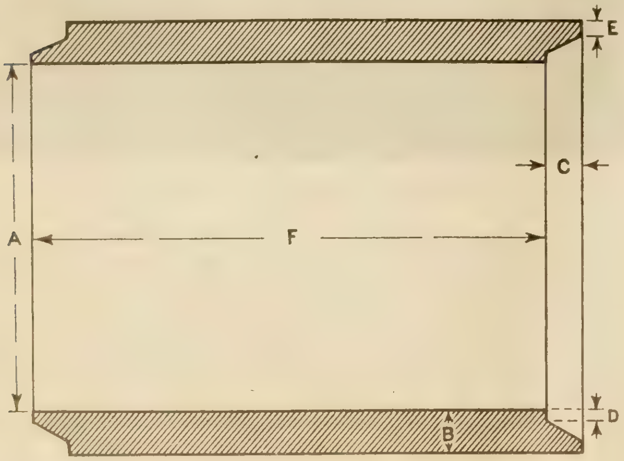


FIG. 5.—Longitudinal section of concrete pipe with beveled-lip joint.

The joints between two successive lengths of corrugated metal pipe were made water-tight by the following method: Strands of oakum were wrapped around the ends of each section in two different corrugations. The collar was then attached and drawn up tightly by means of bolts. The joints were then filled with melted pitch, which, when solidified, gave a water-tight joint. The seams of the individual pipe were soldered.

In testing the various conical entrances each cone was inserted in the inlet end of the culvert pipe, and a false head wall of 1-inch boards was constructed flush with its upstream end. The various wing walls tested were connected directly to the main head wall at the inlet end of the culvert.

DESCRIPTION OF PIPE USED.

Although in actual practice the nominal or commercial size of culvert pipe is always used in computing the cross-sectional area, to determine accurately the retardation factors it was essential in these tests to know the correct average diameter of all pipe tested. For this purpose two diameters at right angles to each other were measured at each end of every pipe used.

These measurements showed that the concrete and the corrugated metal pipe measured practically the nominal or commercial size, while the vitrified clay pipe generally were a little larger than the nominal size. A longitudinal section of the concrete pipe is shown in Figure 5, and a longitudinal section of the vitrified clay pipe tested is given in Figure 6. The dimensions of the concrete pipe are given in Table 1, and those of the clay pipe in Table 2.

TABLE 1.—*Dimensions of concrete pipe.*[1]

A	B	C	D	E	F
Inches.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
12	0.167	0.13	0.06	0.05	2.00
18	.23	.21	.06	.06	2.00
24	.25	.21	.06	.08	3.00
30	.29	.25	.09	.10	3.00

[1] Letter designations refer to Figure 5.

TABLE 2.—*Dimensions of vitrified clay pipe.*[1]

A	B	C	D
Inches.	*Feet.*	*Feet.*	*Feet.*
12	0.09	0.20	0.12
18	.11	.24	.15
24	.13	.28	.18
30	.20	.34	.29

[1] Letter designations refer to Figure 6.

HYDRAULIC ELEMENTS INVOLVED IN DETERMINING CAPACITY OF PIPE CULVERTS.

In order to determine the coefficient of roughness in the culvert pipe and the formula for the carrying capacity of a culvert of any length, the magnitude of each hydraulic element involved in the actual discharge of the culvert must be obtained by experiment. The elements to be determined are: (1) The mean velocity of the water in the culvert; (2) the hydraulic gradient in the pipe; (3) the head lost at the culvert entrance.

Mean velocity.—The method of determining the mean velocity of the water flowing in the pipes involved the measurement of the quantity of water entering the culvert per second, and then solving the relation, *mean velocity equals quantity divided by area of cross section.*

Hydraulic gradient.—The hydraulic gradient was obtained by means of piezometers. Tests were made on the pipe both with a free and with a submerged outlet. When water flows through any culvert, the hydraulic gradient will take the slope required to overcome the retarding effect of the friction acting along the walls of the pipe.

Head lost at the culvert entrance.—The head lost at the culvert entrance is an important factor in the discharge of a culvert and varies greatly with the type of entrance used. This loss in head is determined as fol-

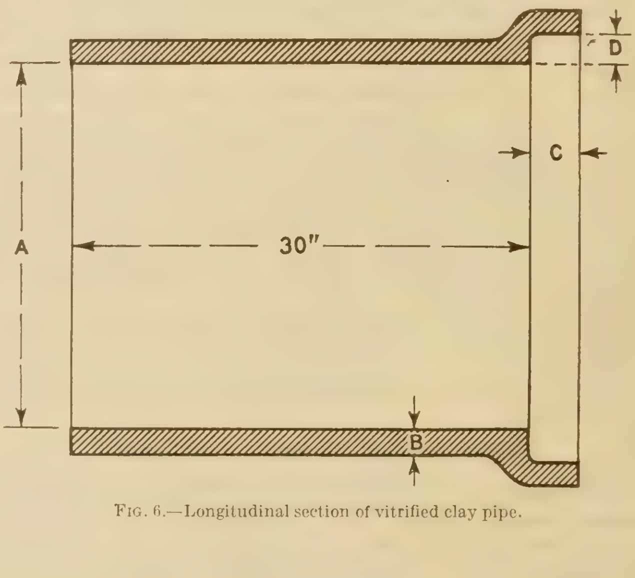


FIG. 6.—Longitudinal section of vitrified clay pipe.

lows: The difference of the elevation of the water surface at the culvert inlet and the elevation of the hydraulic gradient at this point as determined by the piezometer readings is computed. From this amount, called the entrance drop, the velocity head is subtracted, and the remainder is the loss in head for the type of entrance used.

METHOD OF CONDUCTING TESTS.

Tests on each culvert were begun with a head of 0.30 foot of water discharging over the measuring weir, followed by experiments with successive increases of 0.10 foot in head on the weir, until the maximum quantity was obtained which would flow through the pipe without overtopping the bulkhead at the entrance to the culvert. For each head on the measuring weir several different tests were secured by manipulating the bear-trap weir, as follows: (1) With the outlet discharging freely into the air; (2) with the elevation of the water surface at the culvert outlet raised to the middle of the pipe; (3) with the water surface at the outlet brought up to 6 inches below the top of the pipe; (4) with the water surface raised to the top of the pipe at the outlet; (5) with the water surface at the culvert outlet raised by successive increases of 6 inches until the maximum possible submergence was secured.

In obtaining a series of readings for different stages with the outlet submerged and with a constant head on the weir, a set of runs was secured with a constant discharge and having hydraulic gradients approximately parallel in which certain hydraulic elements should check.

Since, in testing the various entrances, the aim was to obtain data on the efficiency of the different types used, only submerged runs were secured. In this case, the first test was begun with a head of 0.4 foot on the weir and was followed by successive increases of 0.1 foot until the maximum quantity was obtained. For each head three different depths of submergence were taken.

An electric bell was placed on the derrick directly over the culvert being tested and was connected with another bell placed on the observation platform at the weir hook gauge. The push button for operating these bells was located at hook gauge No. 2 at the entrance to the culvert pipe.

To secure the data necessary for determining the hydraulic elements for each kind of pipe tested, five men were required, to act in the following capacities:

(1) Observer of piezometers.
(2) Observer at hook gauge No. 1 located at the weir.
(3) Observer at hook gauge No. 2 located at the culvert entrance.
(4) Observer at hook gauge No. 3 located at the culvert outlet.
(5) Man for operating head-gate and bear-trap weir.

PROGRESS OF THE TEST.

From start to finish, a single test progressed as follows:

(1) The head gate was adjusted to obtain the required head on the weir.

(2) The stage of the water surface at the entrance of the culvert was watched to determine when it became steady.

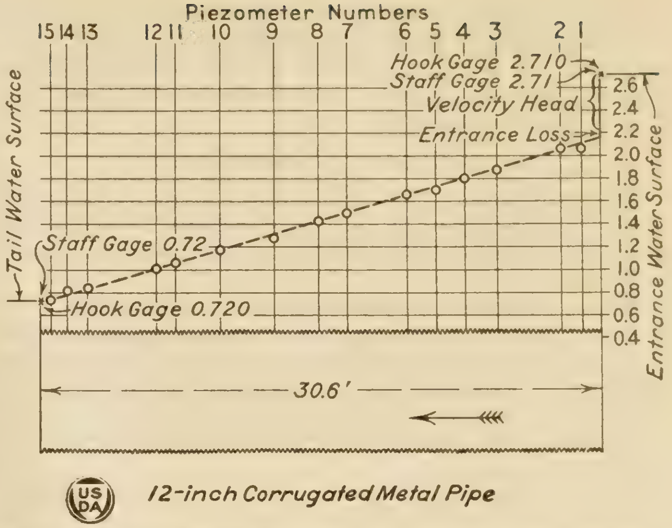


FIG. 7.—Profile of 12-inch corrugated metal pipe with straight end wall entrance.

(3) The test was then ready to begin. Tests were numbered consecutively. The observer at hook gauge No. 2 gave the time of starting to the observer of hook gauge No. 3 and to the observer of piezometers, both of whom recorded this time above the number of the test on their log charts. Two short bells announced that a test was to begin.

(4) Ten seconds later, one short bell gave the time to take the first reading.

(5) One bell every 30 seconds signaled simultaneous readings on all the hook gauges, during which period the piezometers were read.

(6) Readings were continued until 10 consecutive readings on each hook gauge were secured.

(7) Three bells denoted the close of a test.

(8) The observer at hook gauge No. 3 directed the operator to raise the bear-trap weir for the next test.

In having the observer of the piezometers secure single readings on all hook gauges, a check was obtained on the reading of these gauges. Error in reading a gauge is much more apt to occur in the reading of the 0.1 foot than in either the 0.01 or the 0.001 foot. No check was necessary on the readings of the piezometers, as the observer could not possibly retain all of the readings for the first set (15 to 30 in number, depending upon the length of the pipe) in his mind when taking the second set.

As soon as possible after the conclusion of each test the average values of all the different readings were plotted on a diagram which was, in effect, a condensed profile of the pipe under test. (See fig. 7.) Near the right margin of the diagram is shown the headwater level above the entrance to the pipe; at the left margin similarly is shown the tail water level at the outlet of the culvert. Along the pipe in their proper respective positions are shown the elevation of the water in the various piezometer tubes. The diagram shows at once the amount of submergence of each end of the culvert pipe and the total differences in water level between the bays at the two ends of the pipe.

Through the points representing the water level in the various piezometer tubes an average straight line was drawn, as shown in Figure 7. This line represents the hydraulic gradient in the pipe. The diagram shows strikingly that, while at the outlet end of the pipe, if submerged, the hydraulic gradient nearly meets the tail water level—frequently it is slightly below it—on the other hand, at the entrance end of the pipe the hydraulic gradient is often far below the headwater level. The slope of the hydraulic gradient indicates the true friction loss within the pipe.

DISCUSSION OF EXPERIMENTAL RESULTS.

The results of 1,192 tests contained in 58 separate tables (not included in this article) have been studied in detail and from these studies certain conclusions have been drawn.

Effect of depth of submergence.—A study was first made to determine, for a culvert submerged at both ends, whether any definite relation exists between the depth of submergence and the ratios of entrance loss to velocity head and friction loss to velocity head. It was found that these ratios are practically constant, and thus independent of the amount of submergence of the culvert. At the same time it was found that unless the entrance to the pipe was submerged to some extent the pipe would not flow full, and thus would not achieve its full discharging capacity.

Relation of losses to velocity.—To determine the relation between the mean velocity in the pipe and the ratios of entrance loss, friction loss, and total head to velocity head, the mean velocity, mean entrance drop, mean friction loss, and mean total head were determined for each group of tests in which the head on the weir was approximately the same for all the tests in different tables. The average velocity head was computed from the mean velocity for each group. The entrance loss was obtained by subtracting from the mean entrance drop the new velocity head, and this loss divided by the new velocity head to determine the

TABLE 3.—*Summary of results of test data.*

Table No.	Pipe.			Remarks.	Entrance loss co-efficient.	Ratio of velocity head to total head.	Ratio of friction loss to total head.	Ratio of entrance loss to total head.	Equation.
	Kind.	Size.	Length.						
		Inches	*Feet.*			*Per cent.*	*Per cent.*	*Per cent.*	
12	Concrete	12	30	Straight end wall entrance—Pipe with beveled lip	0.111	52.8	41.6	5.6	$Q=4.62\ H^{0.470}$
13	...do	18	30	...do	.097	64.8	29.8	5.4	$Q=11.42\ H^{0.484}$
14	...do	24	30	...do	.093	69.9	25.9	4.2	$Q=20.8\ H^{0.470}$
15	...do	30	30	...do	.137	74.1	20.7	5.2	$Q=33.1\ H^{0.474}$
16	...do	12	30	Straight end wall entrance—Pipe with square end	.276	49.0	37.6	13.4	$Q=4.42\ H^{0.486}$
17	...do	18	30	...do	.404	53.6	25.4	21.0	$Q=10.3\ H^{0.482}$
18	...do	24	30	...do	.437	55.7	20.3	24.0	$Q=18.65\ H^{0.478}$
19	...do	30	30	...do	.493	61.2	14.7	24.1	$Q=29.8\ H^{0.467}$
20	Clay	12	30	Straight end wall entrance	.010	64.8	34.7	0.5	$Q=5.25\ H^{0.482}$
21	...do	18	30	...do	.044	68.5	29.5	2.0	$Q=11.9\ H^{0.505}$
22	...do	24	30	...do	.095	69.6	25.9	4.5	$Q=22.25\ H^{0.481}$
23	...do	30	30	...do	.120	72.6	21.0	6.4	$Q=32.0\ H^{0.485}$
24	Metal	12	30	...do	.160	24.1	72.1	3.8	$Q=3.0\ H^{0.506}$
25	...do	18	30	...do	.200	31.0	63.1	5.9	$Q=7.86\ H^{0.498}$
26	...do	24	30	...do	.225	39.6	52.2	8.2	$Q=15.8\ H^{0.523}$
27	...do	30	30	...do	.295	42.6	45.8	11.6	$Q=24.9\ H^{0.485}$
28	Concrete	24	24	Straight end wall entrance—Pipe with beveled lip	.080	72.0	23.8	4.2	$Q=21.0\ H^{0.485}$
29	...do	24	36	...do	.061	68.7	30.4	.9	$Q=20.45\ H^{0.485}$
30	Clay	24	25	Straight end wall entrance	.122	70.1	22.0	7.9	$Q=22.3\ H^{0.496}$
31	...do	24	38	...do	.057	68.4	29.8	1.8	$Q=21.8\ H^{0.489}$
32	Metal	24	24	...do	.298	42.9	44.4	12.7	$Q=16.5\ H^{0.505}$
33	...do	24	36	...do	.230	36.2	55.8	8.0	$Q=15.1\ H^{0.505}$
34	...do	24	36	Straight end wall entrance (ascending series)	.212	36.0	56.7	7.3	$Q=15.05\ H^{0.481}$
35	...do	24	36	Straight end wall entrance (descending series)	.236	34.8	57.3	7.9	$Q=14.8\ H^{0.500}$
36	...do	24	36	Straight end wall entrance with floor in front of entrance	.436	34.0	50.1	15.9	$Q=14.75\ H^{0.512}$
37	Clay	24	38	Conical entrance, 13° angle, 10 inches long	.110	67.8	26.6	5.6	$Q=21.7\ H^{0.477}$
38	...do	24	38	Conical entrance, 13° angle, 20 inches long	.027	69.4	30.7	—.1	$Q=21.7\ H^{0.473}$
39	...do	24	38	Conical entrance, 45° angle, 10 inches long	.105	67.2	27.0	5.8	$Q=21.8\ H^{0.481}$
40	Metal	24	36	Conical entrance, 13° angle, 10 inches long	.043	38.5	60.1	1.4	$Q=15.65\ H^{0.507}$
41	...do	24	36	Conical entrance, 13° angle, 20 inches long	.040	38.5	60.0	1.5	$Q=15.65\ H^{0.503}$
42	...do	24	36	Conical entrance, 24° 47′ angle, 10 inches long	.050	38.6	60.2	1.2	$Q=15.60\ H^{0.504}$
43	Clay	12	30	12–15-inch standard commercial increaser used as entrance	.128	61.2	31.6	7.2	$Q=5.1\ H^{0.496}$
44	...do	12	30	12–18-inch standard commercial increaser used as entrance	.083	61.2	33.7	5.1	$Q=5.1\ H^{0.496}$
45	...do	18	30	18–20-inch standard commercial increaser used as entrance	.190	62.3	27.2	10.5	$Q=11.3\ H^{0.490}$
46	Metal	24	36	45° wings, full height, set flush with inside edge of pipe, without floor in front of entrance.	.168	37.7	56.4	5.9	$Q=15.5\ H^{0.491}$
47	...do	24	36	45° wings, standard height, set flush with inside edge of pipe, without floor	.243	37.1	54.1	8.8	$Q=15.3\ H^{0.492}$
48	...do	24	36	45° wings, full height, set 6 inches from inside edge of pipe, without floor	.224	36.6	55.5	7.9	$Q=15.25\ H^{0.488}$
49	...do	24	36	45° wings, standard height, set 6 inches from inside edge of pipe, without floor.	.269	37.0	54.2	8.8	$Q=15.25\ H^{0.482}$
50	Clay	24	38	45° wings, full height, set flush with inside edge of bell with floor in front of entrance.	.116	66.9	26.1	7.0	$Q=21.75\ H^{0.475}$
51	...do	24	38	45° wings cut level to top of standard end wall and set flush with inside edge of bell, with floor in front.	.122	67.0	26.1	6.9	$Q=21.55\ H^{0.476}$
52	...do	24	38	45° wings cut on bevel to top of standard end wall and set flush with inside edge of bell, with floor in front.	.111	66.9	26.0	7.1	$Q=21.55\ H^{0.479}$
53	...do	24	38	45° wings, standard height, set flush with inside edge of bell, with floor in front of entrance.	.106	67.6	27.8	4.6	$Q=21.60\ H^{0.479}$
54	Metal	24	36	45° wings, standard height, set flush with inside edge of pipe, with floor in front.	.365	35.7	51.7	12.6	$Q=15.15\ H^{0.486}$
55	Clay	24	38	U-type wings cut on bevel to top of standard end wall and set flush with inside edge of bell, with floor in front of entrance.	.177	63.0	27.8	9.2	$Q=21.05\ H^{0.483}$
56	...do	24	38	U-type wings cut on bevel to top of standard end wall and set 6 inches from inside edge of bell, with floor in front.	.150	65.1	25.6	9.3	$Q=21.35\ H^{0.485}$
57	...do	24	38	U-type wings, standard height, set flush with inside edge of bell, with floor in front of entrance.	.291	58.6	26.9	14.5	$Q=20.35\ H^{0.485}$
58	...do	24	38	U-type wings, standard height, set 6 inches from inside edge of bell, with floor in front of entrance.	.169	61.7	29.4	8.9	$Q=20.70\ H^{0.476}$
59	...do	24	38	Straight end wall with entrance bell filled with concrete and surfaced off straight from inside edge of bell to inside edge of pipe.	.044	68.8	29.1	2.1	$Q=22.05\ H^{0.490}$
60	...do	24	38	Straight end wall with entrance bell filled with concrete elliptically shaped with convex surface out.	.020	69.9	29.1	1.0	$Q=22.2\ H^{0.485}$
61	...do	24	38	Straight end wall with entrance bell filled with concrete shaped to give a square-cornered entrance.	.478	54.8	20.7	24.5	$Q=19.6\ H^{0.485}$
62	Concrete	12	31	3-inch projection beyond head wall—Pipe with square-cornered entrance	.354	45.8	38.0	16.2	$Q=4.28\ H^{0.477}$
63	...do	12	31	24-inch projection beyond head wall—Pipe with square-cornered entrance	.342	46.5	37.8	15.7	$Q=4.32\ H^{0.479}$
64	...do	12	33	47-inch projection beyond head wall—Pipe with square-cornered entrance	.361	45.4	38.4	16.2	$Q=4.26\ H^{0.488}$
65	...do	12	33	47-inch projection beyond head wall—Pipe with beveled lip	.092	50.3	45.1	4.6	$Q=4.47\ H^{0.483}$
66	Metal	18	36	3-inch projection beyond head wall	.314	27.1	64.6	8.3	$Q=7.35\ H^{0.482}$
67	...do	18	36	24-inch projection beyond head wall	.552	25.8	60.1	14.1	$Q=7\ 18\ H^{0.489}$
68	...do	18	36	48-inch projection beyond head wall	.568	25.3	60.5	14.2	$Q=7.12\ H^{0\ 485}$
69	Clay	18	30	Straight end wall entrance 18 to 26 inch cone, 60 inches long at outlet end of pipe, length including cone 30 feet.	.032	64.3	33.3	2.4	$Q=16.45\ H^{0.500}$

average entrance loss ratio. The mean friction loss ratio and mean total head ratio were obtained by dividing the mean friction loss and the mean total head by the new velocity head.

These ratios were plotted on coordinate paper with mean velocity in feet per second as abscissæ and the ratios of entrance loss, friction loss, and total head to velocity head as ordinates.

A study of these diagrams shows that the ratios of the entrance loss, friction loss, and total head to the velocity head are substantially constant, with a slight tendency toward increasing values for the higher velocities. For those tests in which the velocity fell below 3 feet per second the values of the ratios were generally markedly smaller than for the other tests. Since the data in such cases, however, probably were not as precise as in the other cases, it can not be definitely stated whether this apparent tendency indicates a real law or is only due to unavoidable errors in the measurements. The fact that these ratios were so nearly constant in each table proves that for any given installation the friction loss, the entrance loss, and the total loss are practically proportional to the square of the velocity of the water flowing through the pipe. In other words, the discharging capacity of a pipe is proportional to the square root of the head on the pipe.

Drop down at a free outlet.—When the culvert pipe was acting under some head and with a free outlet, it was noted that there was a drop down in the water surface at the outlet of the pipe. The amount of this drop in the water surface below the top of the pipe at the outlet varied both with the size of the pipe and the head on the pipe. This drop was measured in each case.

Methods of reducing entrance losses.—Among the many interesting things revealed by a study of the 58 tables of experimental data is the effect of different types of entrance on the entrance loss. The entrance loss coefficient has been averaged for each type of entrance and kind of pipe (see column 6, Table 3), excluding all tests in which the pipe velocity was less than 2.50 feet per second. The reason that velocities less than 2.50 feet per second were ignored in finding averages was that for such low velocities the values are less accurately determined than in the other cases. Negative entrance loss values were included and added algebraically. The average shown in Table 3 is a weighted average obtained by dividing the sum of the entrance losses by the sum of the velocity heads.

VALUES OF THE COEFFICIENT OF ROUGHNESS IN THE KUTTER AND MANNING FORMULAS.

The values of the coefficient of roughness in the Kutter and Manning formulas obtained for the individual tests have been averaged for the various pipes.

Since for heads of less than 0.40 foot on the weir the Bazin formula, used for determining the discharge over sharp-crested rectangular weirs of the suppressed type, gives quantities somewhat greater than those obtained by volumetric measurement, the values of the coefficient of roughness for tests with heads of less than 0.40 foot may be a little less than the correct ones. Therefore in obtaining the average values for the coefficient of roughness in the tables of the experimental results all tests with heads of less than 0.40 foot on the weir have been omitted. The average values of the coefficient of roughness in the Kutter and Manning formulas for the various sizes of the three kinds of pipe tested are shown in Table 4.

TABLE 4.—*Average values of the coefficient of roughness in concrete, vitrified clay, and corrugated metal culvert pipe.*

Diameter of pipe.	Kutter coefficient.			Manning coefficient.		
	Concrete.	Clay.	Metal.	Concrete.	Clay.	Metal.
Inches.						
12	0.0117	0.0101	0.0194	0.0119	0.0098	0.0228
18	.0121	.0119	.0217	.0121	.0118	.0248
24	.0130	.0127	.0216	.0130	.0125	.0239
30	.0127	.0131	.0232	.0125	.0131	.0254

This table shows that the coefficient of roughness in the Kutter formula is nearly twice as great for the corrugated metal pipe as for the concrete and vitrified clay pipe. The coefficient of roughness increases with an increase in the size of the pipe. The Manning coefficient for the metal pipe is also approximately twice the value for the concrete and clay pipe, and likewise increases with an increase in the size of the pipe.

The variation of the different values of the Manning coefficient is about the same as that of the Kutter coefficient, showing that throughout the range covered by these tests and so far as indicated by these results, the Manning coefficient is at least as satisfactory as the Kutter coefficient. For the smoother pipe the Kutter and Manning coefficients are practically the same as they are supposed to be. It must be noted, however, that for the rougher pipe the Manning coefficient is definitely higher than the Kutter coefficient, so that for this case it is not safe to use the coefficients as exactly interchangeable. Most coefficients increase for the larger diameters of pipes, indicating that neither the Kutter formula nor the Manning formula makes the correct allowance for change in diameter of pipe. The results indicate that in the Manning formula the value two-thirds, used as the exponent of the hydraulic radius, is too large.

Figures 8, 9 and 10 show the flow of the water in the different kinds of pipe.

COMPARISON OF CARRYING CAPACITY OF CONCRETE, VITRIFIED CLAY, AND CORRUGATED METAL PIPE CULVERTS.

The data presented in Table 3 constitute a condensed summary of the hydraulic elements most useful in making comparisons of the various culvert pipes.

The ratios of velocity head, friction loss, and entrance loss to the total head on the pipe have been determined and expressed in percentages. These percentages, as given in Table 3, are the averages for each kind of pipe for all heads of 0.40 foot and over on the measuring weir. Negative entrance losses have been included and added algebraically.

The ratios of velocity head, friction loss, and entrance loss to the total head on the pipe were plotted on rectangular cross-section paper as ordinates against the respective sizes of pipe as abscissæ. These curves are shown in Figure 11. They are of special importance, as they show that of the total head on the pipe, the percentage consumed in entrance loss and velocity head increases with an increase in the size of the pipe, whereas the percentage required by friction loss decreases with an increase in the size of the pipe. On account of this fact the relative difference in the carrying capacity of a 30-inch vitrified clay and a 30-inch corrugated metal pipe culvert under the same head is much less than the relative difference in the carrying capacity of a 12-inch vitrified clay and a 12-inch corrugated metal pipe culvert.

From the data in the tables of the experimental results, a discharge equation for each table was derived for the various kinds of culvert pipe. By plotting on logarithmic paper the total head on the pipe for each test as abscissa against discharge as ordinate, an expression, $Q = KH^x$, was obtained in which K is the intercept on the unity vertical axis and ^{x} is the slope of the line. These individual discharge equations are given in Table 3 opposite their respective table numbers.

It will be noted from an examination of these individual discharge equations that the exponent of H varies from 0.467 to 0.523, 11 being 0.500 or over and 47 being less than 0.500. The average of the exponents for all the concrete pipe with the beveled-lip end upstream is 0.478. The average exponent for the concrete pipe with a square-cornered entrance is also 0.478. The average exponent for the vitrified clay pipe with the bell-end upstream is 0.491. The average exponent for the corrugated metal pipe is 0.504. These four averages are for the pipe culverts with straight end wall entrances only. The average of the exponents for the 58 tables of experimental results is 0.488. Since this average is nearly 0.500 and since it is common practice to accept the theory that the discharge varies as the square root of the head, it was decided to adopt the value of 0.500 as the exponent of H for subsequent calculations.

FIG. 8.—Water flowing in 24-inch concrete pipe. Depth of flow 1.62 feet, discharge 19.09 second-feet. Note smooth lines of flow.

The exponent of H for the individual discharge equations varies somewhat. The value of the intercepts for the individual equations depends upon the slope of the line which is represented by the exponent of H. The values obtained for the intercepts when the slopes of the lines representing the individual pipe formulas were changed to 0.500 will vary somewhat and it was decided to use approximately the intercepts obtained in the original formulas in deriving the general discharge equations applicable to pipe culverts of any size.

DISCHARGE EQUATIONS DEVELOPED.

It was found that in laying the pipe culverts, the average length was approximately 30.6 feet, so this figure was adopted as a base. Therefore, for the purpose of obtaining a comparison of the carrying capacities of various sizes of concrete, vitrified clay, and corrugated metal pipe culverts having the same length, discharge equations have been derived from the experimental data by the theory of least squares.

FIG. 9.—Water flowing in 24-inch vitrified clay pipe. Depth of flow 1.82 feet, discharge 20.95 second-feet.

These general discharge equations for pipe culverts, 30.6 feet long with straight end-wall entrances are as follows:

Concrete pipe with beveled-lip end upstream.

$$Q = 4.61\ D^{2.18}\ H^{0.50} \qquad (1)$$

Concrete pipe with square-cornered entrance.

$$Q = 4.40\ D^{2.09}\ H^{0.50} \qquad (2)$$

Vitrified clay pipe with regular bell end upstream.

$$Q = 5.07\ D^{2.05}\ H^{0.50} \qquad (3)$$

Corrugated metal pipe.

$$Q = 3.10\ D^{2.31}\ H^{0.50} \qquad (4)$$

in which Q = discharge in cubic feet per second.
D = diameter of pipe in feet.
H = total head on pipe or the difference in the water level at the two ends of the pipe.

By computing the friction loss per unit of length for each size and kind of pipe, and determining by the theory of least squares the equations involving this

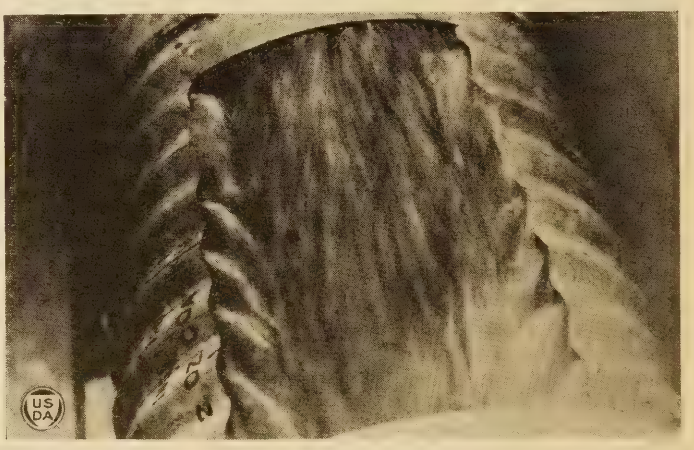


FIG. 10.—Water flowing in 24-inch corrugated metal pipe. Depth of flow 1.82 feet, discharge 17.88 second-feet. Note disturbance of filaments of flow due to corrugations.

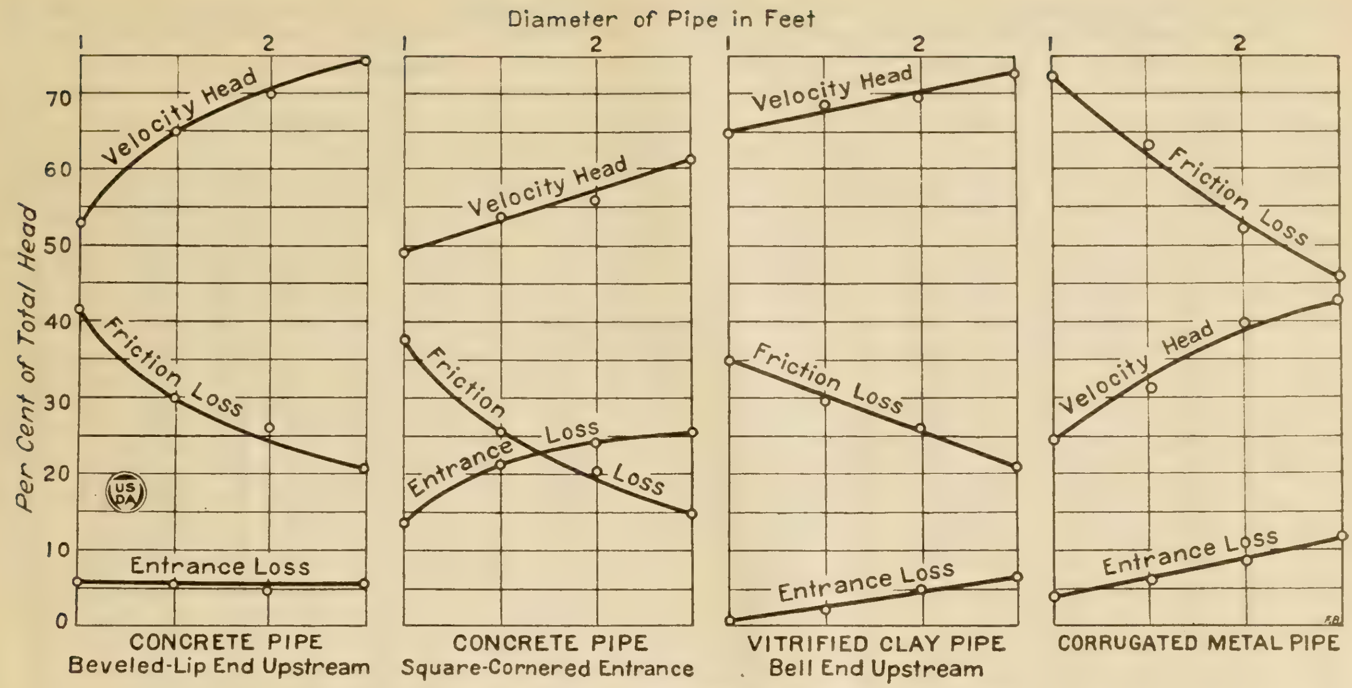


FIG. 11.—Losses in pipe culverts with straight end wall entrances. Length, 30 feet.

factor and the diameter of pipe, discharge formulas have been derived for concrete, vitrified clay, and corrugated metal pipe culverts of any length.

These formulas, which are applicable to lengths between 20 and 60 feet, are as follows:

Concrete pipe with beveled-lip end upstream:

$$Q=\frac{4.61\ D^{2.18}\ H^{0.50}}{\sqrt{1+\frac{0.0138\ (L-30.6)}{D^{0.756}}}} \quad (5)$$

Concrete pipe with square-cornered entrance:

$$Q=\frac{4.40\ D^{2.09}\ H^{0.50}}{\sqrt{1+\frac{0.0127\ (L-30.6)}{D^{1.01}}}} \quad (6)$$

Vitrified clay pipe with bell end upstream:

$$Q=\frac{5.07\ D^{2.05}\ H^{0.50}}{\sqrt{1+\frac{0.0117\ (L-30.6)}{D^{0.526}}}} \quad (7)$$

Corrugated metal pipe:

$$Q=\frac{3.10\ D^{2.31}\ H^{0.50}}{\sqrt{1+\frac{0.0240\ (L-30.6)}{D^{0.489}}}} \quad (8)$$

To represent the experimental values of discharge by one formula for each material which gives the proper weight and effect to the size and length of pipe is a very difficult matter. The usual formula for flow in pipes was tried. The type of this formula is as follows:

$$Q=\frac{\sqrt{2gH}\ A}{\left[1+K_e+\frac{fL}{D^x}\right]^{\frac{1}{2}}} \quad (9)$$

in which Q = discharge in cubic feet per second.
H = head on the pipe in feet.
A = area of pipe in square feet.
D = diameter of pipe in feet.
L = length of pipe in feet.
K_e = entrance loss coefficient.
f = friction loss coefficient.

It was at once apparent, however, that in these experimental results K_e is not a constant but varies with the diameter and length of the pipe. A partial trial of the results showed also that f and ^{x} are variable and can not be rigorously determined from these data. Further investigation will be necessary to determine whether a formula of the type of equation 9 can be used for flow in short pipes and what adaptations of it may be necessary. Because formula 9 is so complicated in form, a simple exponential type of formula was tried to see how it would represent the experimental results. Formulas 1 to 8 given above were found to represent the data throughout the range covered very satisfactorily.

Discharge tables have been computed from the general equations 1, 2, 3, and 4 for concrete, virtified clay, and corrugated metal pipe culverts for heads from 0.01 to 3.5 feet for the following sizes of pipe, 12, 15, 18, 21, 24, 30, 36, 42, and 48 inches in diameter. These capacities are shown in Tables 5, 6, 7, and 8.

For the purpose of enabling the highway engineer to determine the size of a pipe culvert of a certain kind when the quantity to be carried, the head on the pipe,

TABLE 5.—*Capacities of concrete pipe culverts, straight end wall entrance, length 30.6 feet, beveled-lip end upstream.*

[Discharge in cubic feet per second.]

Head on pipe.	Size of pipe.								
	12-inch.	15-inch.[1]	18-inch.	21-inch.[1]	24-inch.	30-inch.	36-inch.[1]	42-inch.[1]	48-inch.[1]
Feet.									
0.01	0.46	0.75	1.12	1.56	2.09	3.40	5.06	7.08	9.47
.02	.65	1.06	1.58	2.21	2.95	4.80	7.15	10.0	13.4
.03	.80	1.30	1.93	2.70	3.62	5.89	8.76	12.3	16.4
.04	.92	1.50	2.23	3.12	4.18	6.80	10.1	14.2	18.9
.05	1.03	1.68	2.49	3.49	4.67	7.60	11.3	15.8	21.2
.06	1.13	1.84	2.73	3.83	5.12	8.32	12.4	17.3	23.2
.07	1.22	1.98	2.95	4.13	5.53	8.99	13.4	18.7	25.1
.08	1.30	2.12	3.16	4.42	5.91	9.61	14.3	20.0	26.8
.09	1.38	2.25	3.35	4.68	6.27	10.2	15.2	21.2	28.4
.1	1.46	2.37	3.53	4.94	6.61	10.7	16.0	22.4	29.9
.2	2.06	3.35	4.99	6.98	9.34	15.2	22.6	31.6	42.3
.3	2.52	4.11	6.11	8.55	11.4	18.6	27.7	38.8	51.9
.4	2.92	4.74	7.06	9.88	13.2	21.5	32.0	44.8	59.9
.5	3.26	5.30	7.89	11.0	14.8	24.0	35.8	50.0	66.9
.6	3.57	5.81	8.64	12.1	16.2	26.3	39.2	54.8	73.3
.7	3.86	6.27	9.34	13.1	17.5	28.4	42.3	59.2	79.2
.8	4.12	6.71	9.98	14.0	18.7	30.4	45.2	63.3	84.7
.9	4.37	7.11	10.6	14.8	19.8	32.2	48.0	67.1	89.8
1.0	4.61	7.50	11.2	15.6	20.9	34.0	50.6	70.8	94.7
1.2	5.05	8.21	12.2	17.1	22.9	37.2	55.4	77.5	104
1.4	5.45	8.87	13.2	18.5	24.7	40.2	59.8	83.7	112
1.6	5.83	9.48	14.1	19.8	26.4	43.0	64.0	89.5	120
1.8	6.18	10.1	15.0	21.0	28.0	45.6	67.8	94.9	127
2.0	6.52	10.6	15.8	22.1	29.5	48.1	71.5	100	134
2.2	6.84	11.1	16.6	23.2	31.0	50.4	75.0	105	140
2.4	7.14	11.6	17.3	24.2	32.4	52.6	78.3	110	147
2.6	7.43	12.1	18.0	25.2	33.7	54.8	81.5	114	153
2.8	7.71	12.6	18.7	26.1	35.0	56.9	84.6	118	158
3.0	7.98	13.0	19.3	27.1	36.2	58.9	87.6	123	164
3.2	8.25	13.4	20.0	27.9	37.4	60.8	90.5	127	169
3.4	8.50	13.8	20.6	28.8	38.5	62.7	93.2	130	175
3.5	8.62	14.0	20.9	29.2	39.1	63.6	94.6	132	177

NOTE.—This table is based on the formula $Q=4.61\ D^{2.18}\ H^{0.50}$, in which Q=discharge in cubic feet per second. D=diameter of pipe in feet, and H=head on pipe in feet.

[1] No experiments were made on these sizes.

TABLE 6.—*Capacities of concrete pipe culverts, straight end wall entrance, length 30.6 feet, square-cornered entrance.*

[Discharge in cubic feet per second.]

Head on pipe.	Size of pipe.								
	12-inch.	15-inch.[1]	18-inch.	21-inch.[1]	24-inch.	30-inch.	36-inch.[1]	42-inch.[1]	48-inch.[1]
Feet.									
0.01	0.44	0.70	1.03	1.42	1.87	2.99	4.37	6.03	7.98
.02	.62	0.99	1.45	2.00	2.65	4.22	6.18	8.53	11.3
.03	.76	1.21	1.78	2.45	3.24	5.17	7.57	10.4	13.8
.04	.88	1.40	2.05	2.83	3.75	5.97	8.74	12.1	16.0
.05	.98	1.57	2.30	3.17	4.19	6.68	9.77	13.5	17.8
.06	1.08	1.72	2.52	3.47	4.59	7.32	10.7	14.8	19.5
.07	1.16	1.86	2.72	3.75	4.96	7.90	11.6	16.0	21.1
.08	1.24	1.98	2.90	4.01	5.30	8.45	12.4	17.1	22.6
.09	1.32	2.10	3.08	4.25	5.62	8.96	13.1	18.1	23.9
.1	1.39	2.22	3.25	4.48	5.92	9.44	13.8	19.1	25.2
.2	1.97	3.14	4.59	6.34	8.38	13.4	19.6	27.0	35.7
.3	2.41	3.84	5.62	7.76	10.3	16.4	23.9	33.0	43.7
.4	2.78	4.44	6.49	8.96	11.9	18.9	27.7	38.2	50.4
.5	3.11	4.96	7.26	10.0	13.3	21.1	30.9	42.7	56.4
.6	3.41	5.43	7.95	11.0	14.5	23.1	33.9	46.7	61.8
.7	3.68	5.87	8.59	11.9	15.7	25.0	36.6	50.5	66.7
.8	3.94	6.27	9.18	12.7	16.8	26.7	39.1	54.0	71.3
.9	4.17	6.65	9.74	13.4	17.8	28.3	41.5	57.2	75.7
1.0	4.40	7.01	10.3	14.2	18.7	29.9	43.7	60.3	79.8
1.2	4.82	7.68	11.3	15.5	20.5	32.7	48.0	66.1	87.4
1.4	5.21	8.30	12.2	16.8	22.2	35.3	51.7	71.4	94.4
1.6	5.57	8.87	13.0	17.9	23.7	37.8	55.3	76.3	101
1.8	5.90	9.41	13.8	19.0	25.1	40.1	58.6	80.9	107
2.0	6.22	9.92	14.5	20.0	26.5	42.2	61.8	85.3	113
2.2	6.53	10.4	15.2	21.0	27.8	44.3	64.8	89.5	118
2.4	6.82	10.9	15.9	21.9	29.0	46.3	67.7	93.5	124
2.6	7.10	11.3	16.6	22.9	30.2	48.2	70.5	97.3	129
2.8	7.36	11.7	17.2	23.7	31.4	50.0	73.2	101	133
3.0	7.62	12.2	17.7	24.5	32.5	51.7	75.7	105	138
3.2	7.87	12.6	18.4	25.3	33.5	53.4	78.2	108	143
3.4	8.11	12.9	18.9	26.1	34.5	55.1	80.6	111	147
3.5	8.23	13.1	19.2	26.5	35.1	55.9	81.8	113	149

NOTE.—This table is based on the formula $Q=4.40\ D^{2.09}\ H^{0.50}$, in which Q=discharge in cubic feet per second. D=diameter of pipe in feet, and H=head on pipe in feet.

[1] No experiments were made on these sizes

TABLE 7.—*Capacities of vitrified clay pipe culverts, straight end wall entrance, length 30.6 feet, regular bell end upstream.*

[Discharge in cubic feet per second.]

Head on pipe.	Size of pipe.								
	12-inch.	15-inch.[1]	18-inch.	21-inch.[1]	24-inch.	30-inch.	36-inch.[1]	42-inch.[1]	48-inch.[1]
Feet.									
0.01	0.51	0.80	1.16	1.60	2.10	3.32	4.82	6.61	8.69
.02	.72	1.13	1.65	2.26	2.97	4.69	6.82	9.35	12.3
.03	.88	1.39	2.02	2.77	3.64	5.75	8.35	11.5	15.1
.04	1.01	1.60	2.33	3.19	4.20	6.63	9.64	13.2	17.4
.05	1.13	1.79	2.60	3.57	4.69	7.42	10.8	14.8	19.4
.06	1.24	1.96	2.85	3.91	5.14	8.13	11.8	16.2	21.3
.07	1.34	2.12	3.08	4.22	5.56	8.78	12.8	17.5	23.0
.08	1.43	2.27	3.29	4.52	5.94	9.38	13.6	18.7	24.6
.09	1.52	2.40	3.49	4.79	6.30	9.95	14.5	19.8	26.1
.1	1.60	2.53	3.68	5.05	6.64	10.5	15.2	20.9	27.5
.2	2.27	3.58	5.21	7.14	9.39	14.8	21.6	29.6	38.9
.3	2.78	4.39	6.38	8.75	11.5	18.2	26.4	36.2	47.6
.4	3.21	5.07	7.36	10.1	13.3	21.0	30.5	41.8	55.0
.5	3.58	5.66	8.23	11.3	14.9	23.5	34.1	46.8	61.5
.6	3.93	6.21	9.02	12.4	16.3	25.7	37.3	51.2	67.4
.7	4.24	6.70	9.74	13.4	17.6	27.8	40.3	55.3	72.7
.8	4.53	7.16	10.4	14.3	18.8	29.7	43.1	59.1	77.8
.9	4.81	7.60	11.0	15.2	19.9	31.5	45.7	62.7	82.5
1.0	5.07	8.01	11.6	16.0	21.0	33.2	48.2	66.1	86.9
1.2	5.55	8.78	12.8	17.5	23.0	36.3	52.8	72.4	95.3
1.4	6.00	9.48	13.8	18.9	24.8	39.3	57.0	78.2	103
1.6	6.41	10.1	14.7	20.2	26.6	42.0	61.0	83.6	110
1.8	6.80	10.8	15.6	21.4	28.2	44.5	64.7	88.7	117
2.0	7.17	11.3	16.5	22.6	29.7	46.9	68.2	93.5	123
2.2	7.52	11.9	17.3	23.7	31.1	49.2	71.5	98.1	129
2.4	7.85	12.4	18.0	24.7	32.5	51.4	74.7	102	135
2.6	8.18	12.9	18.8	25.8	33.9	53.5	77.7	107	140
2.8	8.48	13.4	19.5	26.7	35.1	55.5	80.7	111	145
3.0	8.78	13.9	20.2	27.7	36.4	57.5	83.5	115	151
3.2	9.07	14.3	20.8	28.6	37.6	59.3	86.2	118	156
3.4	9.36	14.8	21.5	29.4	38.7	61.2	88.9	122	160
3.5	9.48	15.0	21.8	29.9	39.3	62.1	90.2	124	163

NOTE.—This table is based on the formula $Q=5.07\ D^{2.05}\ H^{0.50}$, in which Q=discharge in cubic feet per second, D=diameter of pipe in feet, and H=head on pipe in feet.

[1] No experiments were made on these sizes.

TABLE 8.—*Capacities of corrugated metal pipe culverts, straight end wall entrance, length 30.6 feet.*

[Discharge in cubic feet per second.]

Head on pipe.	Size of pipe.								
	12-inch.	15-inch.[1]	18-inch.	21-inch.[1]	24-inch.	30-inch.	36-inch.[1]	42-inch.[1]	48-inch.[1]
Feet.									
0.01	0.31	0.52	0.79	1.13	1.54	2.57	3.92	5.60	7.62
.02	.44	.73	1.12	1.60	2.17	3.64	5.55	7.92	10.8
.03	.54	.90	1.37	1.96	2.66	4.46	6.79	9.70	13.2
.04	.62	1.04	1.58	2.26	3.07	5.15	7.84	11.2	15.3
.05	.69	1.16	1.77	2.52	3.44	5.76	8.77	12.5	17.0
.06	.76	1.27	1.94	2.77	3.77	6.31	9.61	13.7	18.7
.07	.82	1.37	2.09	2.99	4.07	6.81	10.4	14.8	20.2
.08	.88	1.47	2.24	3.19	4.35	7.28	11.1	15.8	21.6
.09	.93	1.56	2.37	3.39	4.61	7.72	11.8	16.8	22.9
.1	.98	1.64	2.50	3.57	4.86	8.14	12.4	17.7	24.1
.2	1.39	2.32	3.54	5.05	6.87	11.5	17.5	25.0	34.1
.3	1.70	2.84	4.33	6.18	8.42	14.1	21.5	30.7	41.8
.4	1.96	3.28	5.00	7.14	9.72	16.3	24.8	35.4	48.2
.5	2.19	3.67	5.59	7.98	10.9	18.2	27.7	39.6	53.9
.6	2.40	4.02	6.13	8.75	11.9	19.9	30.4	43.4	59.1
.7	2.59	4.34	6.62	9.45	12.9	21.5	32.8	46.9	63.8
.8	2.77	4.64	7.07	10.1	13.8	23.0	35.1	50.1	68.2
.9	2.94	4.92	7.50	10.7	14.6	24.4	37.2	53.1	72.3
1.0	3.10	5.19	7.91	11.3	15.4	25.7	39.2	56.0	76.2
1.2	3.40	5.69	8.66	12.4	16.8	28.2	43.0	61.3	83.5
1.4	3.67	6.14	9.36	13.4	18.2	30.5	46.4	66.3	90.2
1.6	3.92	6.57	10.0	14.3	19.4	32.6	49.6	70.8	96.4
1.8	4.16	6.96	10.6	15.2	20.6	34.5	52.6	75.1	102
2.0	4.38	7.34	11.2	16.0	21.7	36.4	55.5	79.2	108
2.2	4.60	7.70	11.7	16.8	22.8	38.2	58.2	83.0	113
2.4	4.80	8.04	12.3	17.5	23.8	39.9	60.8	86.8	118
2.6	5.00	8.37	12.8	18.2	24.8	41.5	63.2	90.3	123
2.8	5.19	8.69	13.2	18.9	25.7	43.1	65.6	93.7	128
3.0	5.37	8.99	13.7	19.6	26.6	44.6	67.9	97.0	132
3.2	5.55	9.29	14.2	20.2	27.5	46.1	70.2	100	136
3.4	5.72	9.57	14.6	20.8	28.4	47.5	72.3	103	141
3.5	5.80	9.71	14.8	21.1	28.8	48.2	73.4	105	143

NOTE.—This table is based on the formula $Q=3.10\ D^{2.31}\ H^{0.50}$, in which Q=discharge in cubic feet per second, D=diameter of pipe in feet, and H=head on pipe in feet.

[1] No experiments were made on these sizes.

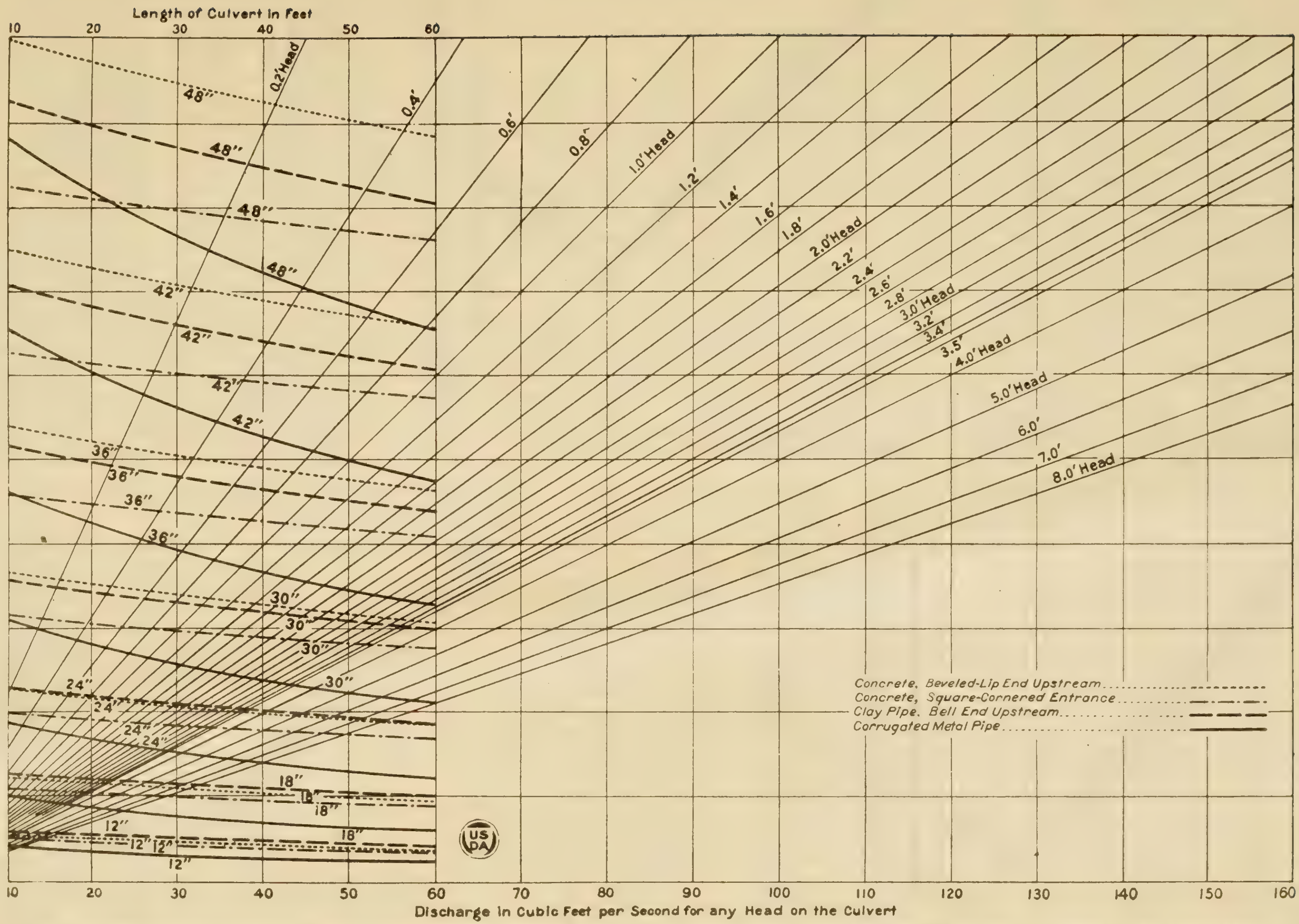


FIG. 12.—Diagram for determining the size of pipe culverts of any length required to carry a known quantity of water under a given head. For culverts with straight end wall entrances only.

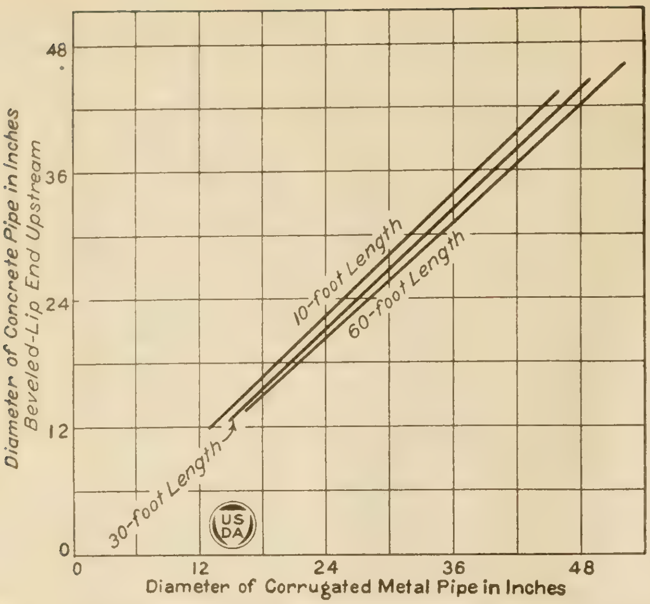


FIG. 13.—Diagram for concrete pipe culverts with beveled-lip end upstream and corrugated metal pipe culverts showing equivalent sizes when discharging the same quantity. Pipe acting under a head of 1 foot—straight end wall entrance.

and the length of the culvert are known, Figure 12 has been compiled from the discharge formulas deduced from the test data. This diagram is useful since no computations are required to obtain the desired information.

Discharge capacity in cubic feet per second for any head on the culvert has been plotted as abscissæ against discharge in cubic feet per second for a head of 1 foot on the culvert as ordinates. From the lower left-hand origin diagonal lines representing the different heads on the culvert have been drawn. On the left side of the diagram, lines representing different sizes of culverts have been established, using length of

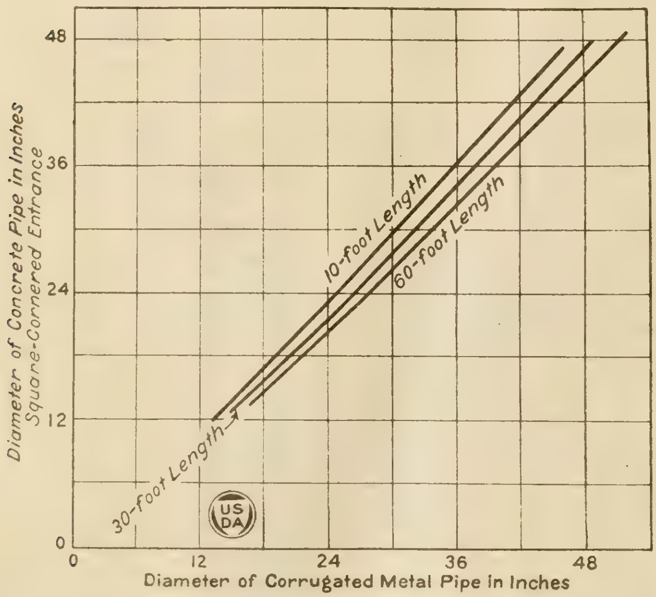


FIG. 14.—Diagram for concrete pipe culverts with square-cornered entrance and corrugated metal pipe culverts showing equivalent sizes when discharging the same quantity. Pipe acting under a head of 1 foot—straight end wall entrance.

culvert in feet as abscissa against discharge in cubic feet per second for a head of 1 foot on the culvert as ordinate.

This diagram is used as follows: Let us assume we desire the size of a vitrified clay pipe culvert 40 feet long when 113 second-feet is to be carried by the culvert. From the highway construction data it is determined that 3 feet is the maximum safe head to use on the culvert. Find 113 second-feet on the abscissa scale. Run up the diagram on a vertical above 113 second-feet to the diagonal line representing a head of 3 feet. From this point run a horizontal line over to the vertical line through the length of the culvert to be used. It is found that a 42-inch clay pipe is required to discharge the required capacity.

Figures 13, 14, and 15 have been compiled for the purpose of showing the equivalent size of pipe culverts when discharging the same quantity of water, the pipe acting under a head of 1 foot.

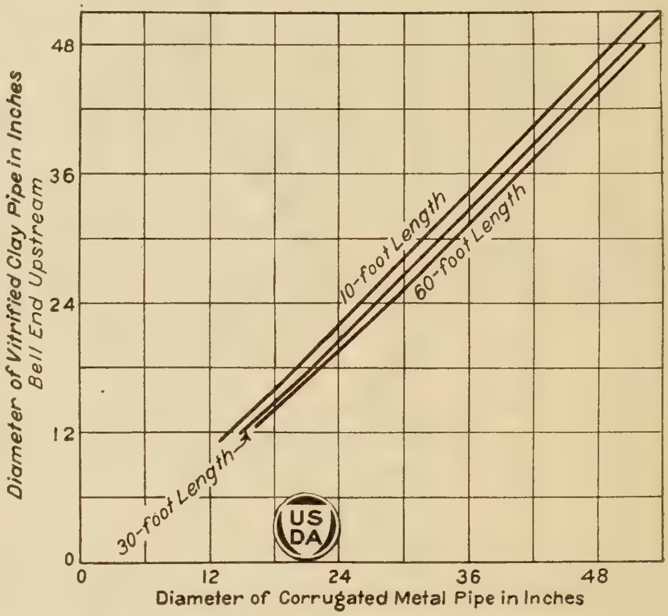


FIG. 15.—Diagram for vitrified clay pipe culverts with bell end upstream and corrugated metal pipe culverts showing equivalent sizes when discharging the same quantity. Pipe acting under a head of 1 foot—straight end wall entrance.

CONCLUSIONS.

1. The discharging capacity of a pipe culvert depends primarily upon the cross section of the pipe and the difference in water level at the two ends of the culvert.

2. To obtain the maximum discharge, the pipe must be so laid as to insure the full cross section of the pipe being filled by the flowing water.

3. If the pipe is laid at too high an elevation with respect to the water levels at the two ends of the culvert, it will not run full and hence will not attain its maximum capacity.

4. If a culvert pipe is so laid that both its upstream and downstream ends are completely submerged the amount of water which it discharges will be proportional to the square root of the difference in water level at the two ends, and the exact grade at which the culvert pipe is laid has no effect whatever upon its maximum discharging capacity.

5. The coefficient of roughness "N" in the Kutter formula for concrete pipe ranges from 0.012 for the 12-inch size to 0.013 for the 30-inch size.

6. The coefficient of roughness "N" in the Kutter formula for vitrified clay pipe ranges from 0.010 for the 12-inch size to 0.013 for the 30-inch size.

7. The coefficient of roughness "N" in the Kutter formula for corrugated metal pipe ranges from 0.019 for the 12-inch size to 0.023 for the 30-inch size.

8. In concrete, vitrified clay, and corrugated metal pipe culverts, 30.6 feet long, with straight end wall entrances:

(*a*) The 12-inch concrete pipe with beveled-lip end upstream will carry about 49 per cent more water than the 12-inch metal pipe.

(*b*) The 18-inch concrete pipe with beveled-lip end upstream will carry about 40 per cent more water than the 18-inch metal pipe.

(*c*) The 24-inch concrete pipe with beveled-lip end upstream will carry about 36 per cent more water than the 24-inch metal pipe.

(*d*) The 30-inch concrete pipe with beveled-lip end upstream will carry about 32 per cent more water than the 30-inch metal pipe.

(*e*) The 12-inch clay pipe will carry about 65 per cent more water than the 12-inch metal pipe.

(*f*) The 18-inch clay pipe will carry about 50 per cent more water than the 18-inch metal pipe.

(*g*) The 24-inch clay pipe will carry about 40 per cent more water than the 24-inch metal pipe.

(*h*) The 30-inch clay pipe will carry about 30 per cent more water than the 30-inch metal pipe.

9. In concrete pipe culverts, 30.6 feet long, with straight end wall entrances:

(*a*) The 12-inch pipe with beveled-lip end upstream will carry about 5 per cent more water than the same pipe with a square-cornered entrance.

(*b*) The 18-inch pipe with beveled-lip end upstream will carry about 9 per cent more water than the same pipe with a square-cornered entrance.

(*c*) The 24-inch pipe with beveled-lip end upstream will carry about 12 per cent more water than the same pipe with a square-cornered entrance.

(*d*) The 30-inch pipe with beveled-lip end upstream will carry about 14 per cent more water than the same pipe with a square-cornered entrance.

10. The effect of the length of the culvert on the discharge is not as great with concrete and vitrified clay pipe as with corrugated metal pipe.

11. The 45° wing walls used in connection with a corrugated metal pipe culvert will increase the capacity from 1 to 10 per cent over that obtained in a metal pipe culvert with a straight end wall.

12. The 45° wing walls used in connection with a corrugated metal pipe culvert are more efficient when set flush with the edge of the pipe than when set 6 inches back from the edge of the pipe.

13. The 45° wing walls used in connection with a corrugated metal pipe culvert are more efficient when built full height to the top of the head wall than when constructed standard height.

14. The 45° wing walls used in connection with a vitrified clay pipe culvert are not as effective as the straight-end wall entrance with the regular bell end upstream.

15. The U-type wings used in connection with a vitrified clay pipe culvert are not as effective as the straight end wall.

16. The beveled-lip end at the entrance of a concrete pipe culvert is a great aid in reducing the entrance loss, especially in the larger sizes.

17. The bell end at the entrance of vitrified clay pipe culvert by virtue of its shape assists greatly in reducing the entrance loss, especially in the smaller sizes.

18. A 24-inch clay pipe culvert, 38 feet long, with a straight end wall and the regular bell end upstream will carry about 10 per cent more water than the same culvert with a square-cornered entrance.

19. By merely rounding the entrance to a 24-inch vitrified clay pipe culvert the capacity may be increased approximately 13 per cent over that obtained with a square-cornered entrance.

20. By projecting the pipe through the head wall so as to obtain the effect of no head wall on the discharge, it was found that—

(*a*) In the 12-inch concrete pipe culvert having a square-cornered entrance, there was little difference whether the pipe projected 3 inches, 2 feet, or 4 feet beyond the head wall.

(*b*) The discharge is decreased slightly by projecting the pipe through the head wall when compared to the same culvert with a straight end wall entrance.

(*c*) The 18-inch corrugated metal with a 3-inch projection beyond the head wall carried slightly more water than the same pipe with either a 2-foot or a 4-foot projection.

(*d*) The 18-inch metal pipe with a straight end wall entrance will carry more water than the same pipe with any length of projection.

21. By increasing the area of the cross section of the outlet end of a pipe culvert so that the area ratio is about 1 to 2, and the angle of divergence about 10°, the discharge of the culvert, when the outlet is submerged, may be increased 40 per cent over that obtained in the same culvert having a uniform bore throughout.

22. The average exponent of H, the head on the pipe culvert, for tables 12 to 69, inclusive, is 0.488. In hydraulics the general practice is to assume that the discharge varies as the square root of the head.

23. New discharge formulas for the flow of water through concrete, vitrified clay, and corrugated metal culvert pipe have been derived from the experimental data. All of these formulas include the loss due to friction in the culvert, the entrance loss, and the velocity head loss. The formulas as derived for culverts 30.6 feet long with straight end wall entrances are as follows:

Concrete pipe with beveled lip end upstream:

$$Q=4.61\ D^{2.18}\ H^{0.50} \qquad (1)$$

Concrete pipe with square-cornered entrance:

$$Q=4.40\ D^{2.09}\ H^{0.50} \qquad (2)$$

Vitrified clay pipe with bell end upstream:

$$Q=5.07\ D^{2.05}\ H^{0.50} \qquad (3)$$

Corrugated metal pipe:

$$Q=3.10\ D^{2.51}\ H^{0.50} \qquad (4)$$

ROAD MATERIAL TESTS AND INSPECTION NEWS.

PUBLIC ROADS will hereafter contain a department which will be of interest primarily to testing and materials engineers, and which will contain notes, comments, and items of general interest in the field of testing and inspection of road materials.

It has been felt for some time that the laboratories of the bureau should keep in closer touch with various State and university testing laboratories and material departments, and it is believed that the publication of items of interest in this field in a special department of PUBLIC ROADS will contribute materially toward this end. The information will take the form of short concise articles dealing with: (1) Special methods of testing which are being used by either the Bureau of Public Roads or the State laboratories; (2) unusual or interesting materials or combinations of materials proposed for use; (3) apparatus used for testing road materials, with special reference to new designs or modified forms, as well as precautions to be observed in connection with its calibration; and (4) the results of cooperative check tests made from time to time by the various State, university, and commercial laboratories.

Testing and materials engineers, chemists, and all others engaged in the testing and inspection of road materials and in highway research are invited to submit articles for publication in this department of PUBLIC ROADS. These contributions may cover any matter of interest in connection with the subjects outlined above. It is believed that there must be an immense amount of information in the possession of the various testing laboratories which would be of interest to others working along the same line. Needless to say, due credit will be given in all cases. Contributions should be addressed to the U. S. Bureau of Public Roads, Washington, D. C., attention Mr. A. T. Goldbeck, Chief, Division of Tests.

COMPARATIVE RESULTS OF CHECK TESTS Sd-4.

On November 8, 1923, the bureau distributed to the various cooperating laboratories mimeographed copies of check tests on a sample of concrete sand, identified as Sd-4. There are a number of points in connection with this check test which are of interest.

In the first place, it will be observed that, whereas most of the laboratories use the so-called American Society for Testing Materials standard sieves for making the sieve analysis, a number of laboratories are using the Tyler standard. The bureau is not prepared to go into a discussion of the relative merits of these two series at this time, except to say that there would appear to be no good reason why some generally accepted standard should not be adopted in the near future. In this connection it might be said that a subcommittee of the Committee on Methods of Tests of the American Society for Testing Materials has recently been organized for the purpose of considering the various standard screen scales for testing sieves, with the object of adopting a standard for general use. Any suggestions relative to this proposed new standard will be welcomed by the committee, and should be forwarded to the chairman, Mr. F. G. Breyer, New Jersey Zinc Co., Palmerton, Pa.

Another point of interest in connection with this test is the fact that numerous laboratories are using samples for the sieve analysis in excess of the weight specified by the Committee on Tests and Investigations of the American Association of State Highway Officials, as published in U. S. Department of Agriculture Bulletin 949. The test as given in this bulletin (Test No. 10, page 12) specifies that the sample shall weigh not less than 100 nor more than 500 grams. Likewise, in connection with the test for silt content, reference to Bulletin 949, test No. 12, shows that the sample for this test should weigh 500 grams. The mimeographed results indicate that a number of laboratories did not use the specified weight. One of the most serious things in connection with this check test, however, is the wide variation in the results of the tensile strength ratio. This may be due to a number of causes. It is believed, however, that the primary reason is the lack of a standard method of estimating normal consistency of the test sand mortar. Variations in the quality of cement used may likewise play a part, as well as variations in methods of manipulation. It is evident that further work must be done on the standardization of this test if the laboratory men expect it to be taken seriously. A review of the temperatures reported by the various laboratories is also interesting in showing that the average temperatures are in all cases above the 21° C. specified as the standard testing temperature for cement.

COMPARATIVE RESULTS OF CHECK TESTS Ct-4.

Several reports have been received of tests made on the check sample of cement sent out to the various laboratories on October 28, 1923. Reports of fineness show great variations in the results obtained. In this connection, the attention of the bureau has been called by the U. S. Bureau of Standards to the fact that 200-mesh testing sieves as now sent out by manufacturers are apt to be far from accurate. It has recently been almost impossible for the Bureau of Standards to secure 200-mesh testing sieves which conform to its requirements regarding size of opening. The attention of the various laboratories is called to the fact that the Bureau of Standards is prepared to calibrate testing sieves for a nominal charge, and anyone who has the slightest doubt as to the accuracy of his sieve is urged to avail himself of this opportunity. In the event that the sieve can not be spared long enough to be sent to Washington for calibration, the Bureau of Standards has arranged to send out standard samples of cement which may be tested on the sieve in question and its accuracy thereby established. The price of these standard samples is 50 cents each.

ASH CORRECTION IN DETERMINATION OF PER CENT BITUMEN.

In examining check test reports on samples of bituminous aggregates it has been noted that in some cases high results for per cent bitumen have been obtained. It is believed that in some instances this may have been caused by not taking cognizance of the fact that in making the tests for per cent bitumen some finely divided mineral matter is almost invariably to be found in the extract. Unless a correction (commonly designated as ash correction) is made for this mineral matter, the results for percentage of bitumen will be high, due to the fact that this mineral matter will be included with the bitumen. Methods for determining this mineral matter are described on page 57 of U. S. Department of Agriculture Bulletin 949.

SUBGRADE STUDIES.

The research work of the subgrade laboratory of the Bureau of Public Roads has progressed to a point which has necessitated the development of several new tests before some of the important characteristics and properties of soils could be properly detected and analyzed. These characteristics are in addition to the properties ordinarily determined by drying, by mechanical analysis, and by slaking. It is necessary to determine the bearing power of different soils as affected by area of bearing block and the percentage of capillary water present in the soil. The amount of silt, clay, and ultraclay must be determined. The water equivalent and the action of the soil under frost conditions is also important. All of these properties and characteristics must be determined before a soil may be properly classified and its action under subgrade conditions predicted. This work has lead to some very important indications relative to the proper treatment of a particular subgrade soil to improve its stability and bearing power. For instance, among other interesting facts, it has been determined that a blanket of sand or other suitable granular material on a subgrade which is more or less continuously wet and soft will prevent this material from working up into a stone subbase or through the voids of the stones forming a macadam road, thus preventing the pumping action so often seen in connection with this type of road. The work so far has been mainly in connection with laboratory and local field conditions, but is now being extended into field work in various localities of the United States. This work will enable the bureau to properly analyze and classify the soils of different sections of the country and to prescribe proper treatment of the subgrade in any particular case to insure its improvement.

PENETRATION LIMITS FOR ASPHALT.

At a conference called by the Division of Simplified Practice, U. S. Department of Commerce, the following penetration limits were adopted and were recommended to become effective on all deliveries of material after January 1, 1924.

For construction of sheet asphalt, asphaltic concrete, and asphalt macadam pavements, and also for surface treatment—Penetration limits.

25 to 30	50 to 60	100 to 120
30 to 40	60 to 70	120 to 150
40 to 50	85 to 100	150 to 200

For joint filler for various types of construction—Penetration limits.

30 to 50	60 to 70
50 to 60	85 to 100

CEMENT TESTING.

Among the much-abused requirements found in the specifications for testing Portland cement is one which reads as follows: "The quantity of dry material to be mixed at one time shall not exceed 1,000 grams nor be less than 500 grams." It is astonishing to observe the false economy practiced in some laboratories in mixing batches for normal consistency or pats. Quantities as small as 50 grams have been mixed and it often happens that 100 and 200 gram batches are used. When it is realized that considerable evaporation and loss of moisture on the mixing table occurs during the manipulation of cement paste and mortar, the necessity for larger batches will be seen. The objection to working more than 1,000 grams at a time is that there is a tendency to undermix the mortar, with consequent production of nonuniform specimens of lowered strength.

NEED FOR A CRUSHED STONE ABRASION TEST.

The value of standardizing some form of stone test which can be applied to the crushed product so as to make car sampling and car testing practicable has been recognized for some time, but so far, apparently, efforts to standardize such a test made have proved unsuccessful. The Bureau of Public Roads has been experimenting for some time in the hope of developing such a test. Further details regarding the method of testing tentatively adopted, as well as some results of a cooperative series of tests made by several laboratories on a sample of stone using this method, will be given in the next News Letter.

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ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS.

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets, nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

REPORTS.

Report of the Director of the Bureau of Public Roads for 1918.
Report of the Chief of the Bureau of Public Roads for 1919.
Report of the Chief of the Bureau of Public Roads for 1920.
Report of the Chief of the Bureau of Public Roads for 1921.
*Report of the Chief of the Bureau of Public Roads for 1922. 5c.
*Report of the Chief of the Bureau of Public Roads for 1923. 5c.

DEPARTMENT BULLETINS.

No. 105. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136. Highway Bonds. 20c.
220. Road Models.
257. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314. Methods for the Examination of Bituminous Road Materials. 10c.
*347. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370. The Results of Physical Tests of Road-Building Rock. 15c.
386. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
387. Public Road Mileage and Revenues in the Southern States, 1914.
388. Public Road Mileage and Revenues in the New England States, 1914.
*389. Public Road Mileage and Revenues in the Central, Mountain, and Pacific States, 1914. 15c.
390. Public Road Mileage in the United States, 1914. A Summary.
*393. Economic Surveys of County Highway Improvement. 35c.
407. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
*463. Earth, Sand-Clay, and Gravel Roads. 15c.
*532. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*537. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
*555. Standard Forms for Specifications, Tests, Reports, and Methods of Sampling for Road Materials. 10c.
583. Reports on Experimental Convict Road Camp, Fulton County, Ga.
*586. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1916. 10c.
*660. Highway Cost Keeping. 10c.
670. The Results of Physical Tests of Road-Building Rock in 1916 and 1917.
*691. Typical Specifications for Bituminous Road Materials. 15c.
*704. Typical Specifications for Nonbituminous Road Materials. 5c.
*724. Drainage Methods and Foundations for County Roads. 20c.
*949 Standard and Tentative Methods of Sampling and Testing Highway Materials, Recommended by the Second Conference of State Highway Testing Engineers and Chemists, February 23 to 27, 1920, 25c.
*1077. Portland Cement Concrete Roads. 15c.
*1132. The Results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.

DEPARTMENT CIRCULAR.

No. 94. TNT as a Blasting Explosive.

FARMERS' BULLETINS.

No. 338. Macadam Roads.
*505. Benefits of Improved Roads. 5c.
597. The Road Drag.

SEPARATE REPRINTS FROM THE YEARBOOK.

No. *727. Design of Public Roads. 5c.
*739. Federal Aid to Highways, 1917. 5c.
*849. Roads. 5c.

OFFICE OF PUBLIC ROADS BULLETIN.

No. *45. Data for Use in Designing Culverts and Short-span Bridges. (1913.) 15c.

OFFICE OF THE SECRETARY CIRCULARS.

No. 49. Motor Vehicle Registrations and Revenues, 1914.
59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.
63. State Highway Mileage and Expenditures to January 1, 1916.
*72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads. 5c.
73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.
74. State Highway Mileage and Expenditures for the Calendar Year 1916.
161. Rules and Regulations of the Secretary of Agriculture for Carrying out the Federal Highway Act and Amendments Thereto.

Public Roads Vol. III, No. 25. Automobile Registrations, Licenses, and Revenues in the United States, 1919.
Vol. III, No. 29. State Highway mileage, 1919.
Vol. III, No. 36. Automobile Registrations, Licenses, and Revenues in the United States, 1920.
Vol. IV, No. 5. Automobile Registrations, January 1 to July 1, 1921.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH.

Vol. 5, No. 17, D- 2. Effect of Controllable Variables Upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 19, D- 3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.
Vol. 5, No. 20, D- 4. Apparatus for Measuring the Wear of Concrete Roads.
Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 10, No. 7, D-13. Toughness of Bituminous Aggregates.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

*Department supply exhausted.

THE HIGHWAY ENGINEER'S CREED

I BELIEVE that transportation is the keystone of the structure of civilization which is built of school, and church, and court, and market place upon the twin foundations of the home and productive industry.

I BELIEVE that highway transportation is a necessary and integral part of this connecting stone in civilization's arch and is coequal with other forms of transportation in sustaining the body of the structure.

I BELIEVE that my mission, as a highway engineer, is to assist in shaping and improving the highways of my country, in harmony with those who provide the vehicles which are their necessary complement, to the end that, joined with other means of transportation, they may meet the need of our people for easy, quick, and untrammelled transportation.